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FINAL REPORT

ON

THE DEVELOPMENT OF CONTOURED INTERLOCKING
TAPE WOUND TITANIUM ROCKET MOTOR CASES

PART I
DESIGN, METALLURGY AND
EXPERIMENTAL FABRICATION

February 15, 1961

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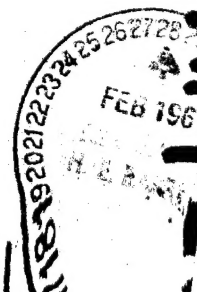
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PLASTICS TECHNICAL EVALUATION CENTER
PICATINNY ARSENAL, DOVER, N. J.

CURTISS-WRIGHT CORPORATION

WOOD-RIDGE, NEW JERSEY

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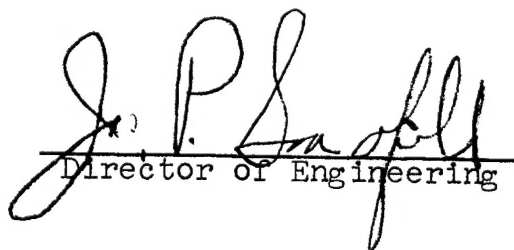
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DESIGN, METALLURGY AND EXPERIMENTAL FABRICATION

Submitted in Partial Fulfillment of U. S. Army
Ordnance Materials Research Office Contract DA-30-069-ORD-3101



Director of Engineering

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Curtiss-Wright Corporation
Wright Aeronautical Division
Wood-Ridge, New Jersey

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1.0 INTRODUCTION

The development of pressure vessels for use in solid fuel rocket motor cases has reached a state wherein further progress may be restricted by lack of suitable high strength metals and limitations in methods of fabrication. Though the potentially high strength to weight ratio of fiber reinforced cases is recognized, the use of metallic cases offers certain advantages peculiar to metals alone.

The application of metal wire or tape as reinforcement in pressure vessels dates back at least a century. High-tensile steel wire has been used as the banding material on certain rifles and guns as well as in other hollow bodies (1). With the possible exception of one recent investigation (2, 3) no attempt has been made to utilize the transverse strengths of wire or tape to support the axial stress in pressurized vessels. Valenta (2) describes vessels reinforced with wound profile strip which is shrunk on to a vessel (while simultaneously quenched to high strength), putting the monolithic portion of the vessel into compression. Though the tape is contoured and interlocked, it does not appear to support any of the axial load. The present report describes a means whereby the transverse strength of severely cold reduced tape is fully utilized. The method simultaneously facilitates application of ultra high strength materials which might otherwise be difficult or impossible to use.

The interlocking titanium tape concept is an outgrowth of relatively recent work carried out by this contractor (4) in the development of the high strength titanium alloy B12OVCA. In sheet form, this alloy is heat-treatable to a yield strength of 180,000 psi, a strength level which on a strength-to-weight basis is higher than that of the best ferrous materials used in rocket motor casings today. Unfortunately, this alloy is difficult to weld and even a successful weld cannot be heat treated to maximum strength because the aging response of base material and weldment differ considerably. It was observed that this alloy, similarly to most precipitation hardenable alloys, benefits considerably as a result of cold work prior to aging. Thus, the useful strength level of B12OVCA can be increased to 300,000 psi, a strength which if fully utilized in a pressure vessel would result in a strength-to-weight ratio of about 1.7×10^6 in.

1.0 INTRODUCTION (Continued)

The objectives of the present contract consisted primarily of the development of fabrication and metallurgical procedures for the manufacture of two basic structural shapes, the development of a wrapping machine and finally the experimental manufacture of two sub-scale vessels. These objectives have been met.

The Curtiss-Wright Corporation wishes to acknowledge financial support from the U. S. Army through the Ordnance Materials Research Office. The assistance of Dr. J. L. Martin, Messrs. G. A. Darcy, Jr. and I. Kahn of that Office as well as of Messrs. R. L. Weatherington and C. H. Martens of the U. S. Army Rocket and Guided Missile Agency is gratefully acknowledged.

2.0 SUMMARY

During the contract period, June 15, 1960 to January 14, 1961, the Wright Aeronautical Division of the Curtiss-Wright Corporation has pursued the work program as originally detailed in the Proposal (5) and has demonstrated the feasibility of interlocked tape wound pressure vessels from both the metallurgical and experimental manufacturing standpoint. Demonstration of the design concept as based on hydrostatic pressure and other environmental tests will be carried out as part of a proposed follow-on to the present contract (6).

"I" beam and channel shapes were designed, fabricated and tested. Turks heading was selected in preference to die drawing, though the latter process might be utilized at a future date for final sizing.

A structural rig for experimental verification of stress analysis data has been fabricated. Several techniques for precise determination of tape dimensions have been evaluated resulting in the selection of a metallographic method. A specification for Bl2OVCA titanium starting wire has been written and coordinated with two potential sources. The static coefficients of friction of drawn and heat treated tape have been measured and separate interference fit measurements of the interlock have been carried out. The aging response of both shapes in terms of metallographic structure and mechanical properties have been determined and a final heat treatment selected. The low temperature properties of the Bl2OVCA sheet, including notch sensitivity tests have been determined. Several vessel liner materials and bonding methods have been evaluated.

Vessel wrapping apparatus including dummy arbors, collapsible mandrels and other auxiliary apparatus have been designed, manufactured and utilized in the fabrication of two prototype vessels. Design modifications in tape as well as manufacturing techniques based on experience gained in the present program have been carried out and will be incorporated in the proposed follow-on effort.

3.0 RECOMMENDATIONS FOR FUTURE WORK

Limitations inherent in the "Turks Heading" process of wire manufacture, together with observations made both during interference fit testing and wrapping require that the currently used tape shapes be redesigned to incorporate deeper grooves in both shapes. This will assure greater contact area and permit loosening of tolerances on internal corner radii.

Several changes in the wrapping apparatus, collapsible arbor and mandrel removal will be carried out. Presently used 300M steel used in end adapters will be replaced by 25% nickel iron resulting in a higher available yield strength.

The proposed second phase of the present contract will include experimental manufacture of six pressure vessels which will be subjected to hydrostatic tests. The program will further include such studies and analyses relating to adapter attachment, wrapping technique, tape design, metallurgy and other areas found critical during the course of investigation leading to the development of a practical application of the concept.

4.0 DESIGN AND STRESS

4.0 DESIGN

4.1 Mechanical Design

The feasibility of using a high-strength interlocking tape wrapped vessel for a light-weight rocket motor was investigated from a design and stress point of view. Figure 1 shows the selected interlocking tape configuration of three layers. The configurations analyzed were based on a motor I.D. of 6.2 inches and an operating pressure of 4700 psi. This diameter sub-scale vessel was selected because of the availability of a piston rig adaptable to hydrotesting this vessel. In the stress analysis of this vessel, the effects of the small diameter on bending stresses and elastic instability were neglected. This was done to permit direct up scaling to a larger diameter motor.

The design of the interlocking titanium tape is based on a minimum allowable longitudinal and transverse yield strength of 250,000 psi and total (elastic plus plastic) strain of 4% in the transverse direction.

Based on these mechanical properties, two interlocking configurations were studied with emphasis placed on manufacturing feasibility and minimum weight. Figure 2 (b) shows one arrangement with "full-line" contact between adjacent butted channels; and Figure 2 (a) shows another arrangement resulting in "point" contact (under load) between butted channels. Stress analysis has indicated that the full-line butted contact between adjacent channels produces the more efficient arrangement. The final tape dimensions for both the channel and "I" beam are shown in Figure 3.

Additional stress analysis was performed on the inner channel layer in order to determine the local bending stress in each channel caused by the internal pressure (Figure 4). This bending stress is a result of the longitudinal bending of the channel between "I" beam flanges, and adds directly to the longitudinal stress. However, this condition would not arise in a full-scale rocket motor case since the internal pressure for the same tape stress level would be greatly reduced. The present six inch diameter sub-scale test vessel is designed to yield at 4700 psi pressure, whereas a larger diameter vessel would operate at approximately 1000 psi. To alleviate this local bending stress in the sub-scale vessel, the width of the "I" beam flanges was increased from .025 to .040 inches (Figure 5). This reduces the free beam length of the channel and thus reduces the local bending stress.

4.1 Mechanical Design (Continued)

As seen in Figure 3, the legs of the "I" beam and channels are tapered. This is to permit assembly of the wires under the worst tolerance condition. To insure interlocking of the wire assembly, the "I" beams are pre-stressed in the transverse direction. The theoretical load required to force an "I" beam or channel into position is approximately equal to 2500 pounds. This load should be exerted by a roller of 5 inches minimum diameter. The theoretical axial tension required when wrapping either an "I" beam or channel should not exceed 200 pounds. The 2500 pound applied load required to force the wire into position was calculated on the basis of an assumed coefficient of friction between titanium of 0.2 and a roller contact length of .1 inch. A survey of the literature, later confirmed by direct tests, indicated that this value is low and a value of 0.3 is more realistic. The maximum axial load of 200 pounds results in a residual pre-stress of 50,000 psi for the tape in position on the vessel. This assumes that the entire axial winding load remains in the wrapped tape due to friction along the interlocking surface.

4.2 Stress Analysis

Stress analyses of the butted and spaced channel configurations have been completed. When the channel ends are spaced, it is possible to design channels and "I" beams so that only two different tape shapes are required and any number of layers can be added. This situation will occur when

$t_{1A} = t_{1B}$ and $L_D = L_C$. (See Figure 6 for nomenclature). The spacing between the channels will then equal the spacing between the "I" beams. This arrangement is not ideal from a stress standpoint. The loading on the channels produces bending stresses in addition to the axial stresses. This arrangement also results in a varying load distribution across the wall of the vessel which tends to overstress the inside and outside layers while understressing the middle layers. Thus, the efficiency is reduced.

When the adjacent channel ends are butted, two different shapes of tape are sufficient only when n (the number of "I" beams) is equal to 1 (3 layers) or the spacing between the "I" beams is 0. For all other configurations, more than one shape of "I"

4.2 Stress Analysis (Continued)

beam is required. For optimum hoop stress design, it is desirable to have spacing between the "I" beams; therefore, the case where $n = 1$ is recommended. This case also affords the minimum overall wall thickness. From a stress standpoint, the butted channel arrangement is preferable to the spaced channel arrangement because the channel bending stresses and the varying load distribution across the wall are reduced.

Having established the interlock configuration which yields minimum stresses, an analysis was performed to determine the actual tape dimensions. The butted channel tape configurations were analyzed in detail and the results are shown in Figure 7.

An outline of the stress analysis is given below:

- (a) Consideration of the load in the longitudinal direction determines the shank thicknesses of the "I" beam and the channel. Since there are two channel layers sandwiching an "I" beam layer in a three layer vessel, the shank must be twice as thick as the channel shank. This assumes no pre-stressing of the "I" beam at the interlock. However, an initial compressive prestress imposed on the butted channel ends will tend to maintain line-to-line contact and minimize channel bending.
- (b) The thickness of the interlocking legs is obtained next. For short interlocking leg heights ($\Delta = 0.010$), the allowable shear stress determines the thickness of the leg. In general, this thickness is more than two and one-half times the channel leg height. Since the interlocking legs are relatively short in height and broad in thickness, the interlocking load was assumed to be transmitted in shear without accounting for bending effects.
- (c) The length of the "I" beam must be equal to the sum of twice the channel leg thickness plus twice the "I" beam leg thickness.
- (d) The height of the channel leg (Δ) is determined by the allowable bearing stress on the interlocking joints.

4.2 Stress Analysis (Continued)

- (e) The length of the channel (L_c) is determined last. The metal-filled area of the wall is varied by varying the channel lengths. For an optimum design, the metal-filled area is sized for the allowable vessel hoop stress.

The detailed stress calculations made in determining the final shapes of the "I" beam and channel are shown in Appendix I.

4.3 Weight Estimates

A weight estimate was made to determine the percent weight saving of the titanium tape over a solid wall steel shell of 300M material having a uniaxial yield strength of 200,000 psi minimum. The weight of the tape wrap includes the interlocking tape and the plastic liner. The weight of the interlocking tape shell is 50% less than the weight of the 300M shell (Figure 8).

4.4 End Attachments

The design for attaching the ends of the interlocking tape to the domes is shown schematically in Figure 9. All three layers of tape, after being wrapped around the threaded dome adapter, are held in place by groove pins. (An investigation of other bonding methods was carried out and is reported in Section 5.) Because of the helical winding of the interlocking tape, the natural tendency of the tape under pressure would be to unwind (See Figure 10). The necessary restraint can be attained in three ways: (1) by bonding the interlocking tapes with an epoxy resin to withstand the shearing tendency to unwind; (2) by using a counter-winding combination of layers in which the unwinding tendencies can be mechanically neutralized; (3) by relying on the interference fit between interlocking tapes to withstand the unwinding tendency through friction. Stress analyses have indicated that the torsional shear stresses are low (422 psi) and the friction between tapes will restrain the vessel from unwinding.

Figure 9 shows the adapter to be tapered where the unsupported cylindrical section of the interlocking tape starts. This taper minimizes the discontinuity stresses at the intersection. Under internal pressure the tapered adapter section in contact with the tape will yield radially outward and reduce the discontinuity effects.

4.4 End Attachments (Continued)

Sealing of the vessel against internal pressure can be accomplished by coating the inside of the motor with a layer of vinyl. Vinyl, which has a relatively low modulus of elasticity, is capable of adhering to the tape wrapped vessel without cracking when subjected to the radial and longitudinal strains of the pressurized vessel.

The final design of the sub-scale vessel is shown in Figure 11. This drawing shows details of the tape, adapters, and the assembly. The piston rig, which is used for hydrotesting, is shown in Figure 12.

4.5 Piston Rig - Jacking Fixture

In order to test the operation of the Piston Rig Apparatus, a burst test of a solid 300M steel vessel was carried out. The vessel was pressurized to a burst pressure of 5000 psi without damage to the piston rig. However, in assembling the piston covers containing the hard rubber "O" rings and leather back-up ring, a larger than expected force was required to compress the "O" ring. This force was transmitted through the vessel to ground. Consequently, a jacking fixture was designed and fabricated which will prevent this high compressive force from being transmitted into the vessel. The design of the jacking fixture is shown in Figure 13.

4.6 Structural Rig

A structural rig which will be used to evaluate the interference fit has been designed and fabricated. The purpose of this rig is to determine the parameters which affect the stresses in the tapes. Schematically shown in Figure 14 is a freebody diagram of the channel subjected to the loads resulting from the interference fit. It may be observed that the interference fit tends to clamp the channel flange and prevent rotation during pressurization. Figure 15 shows the apparatus which will be used to evaluate these stresses. The channel sections are fabricated from B120VCA titanium strip and will be ten times the actual cross-sectional dimensions. The clamping plates will also be fabricated from B120VCA titanium. These plates when bolted together will produce an interference fit with the channel sections. Hoop restraint is induced by transverse clamping which simulates the internal pressure effects. The test procedure to be used for this rig is detailed in Appendix II, and the instrumentation layout is shown in Figure 16.

4.7 Roll Redesigns

The following procedure was used to determine the dimensions of the proper finish "I" beam rolls that would yield the correct tape cross-section. The form rolls were not reworked and are shown in Figure 17. Figure 18 shows the finished rolls assembled, the dimensions of the rolls, and the resulting rolled tape dimensions. Since the angle of 17° is more than the desired 12° , a new roll was made (Figure 19) having an angle of 1 to 3° . This roll produced a tape angle of 7.5° . A plot was then constructed (Figure 20) which relates roll angle to tape angle. Based on this data a new roll was made having angles of 4.5 to 5.5° . The resulting tape dimensions are shown in Figure 21. The "I" beam roll width was also changed to produce a greater interference fit.

A similar procedure was carried out for the redesign of finish channel rolls. The form rolls shown in Figure 22 were also not reworked. The first shape rolled is shown in Figure 23, the second in Figure 24, and the third in Figure 25. A plot of channel roll angle versus tape angle is shown in Figure 26.

TYPICAL WIRE CONFIGURATION

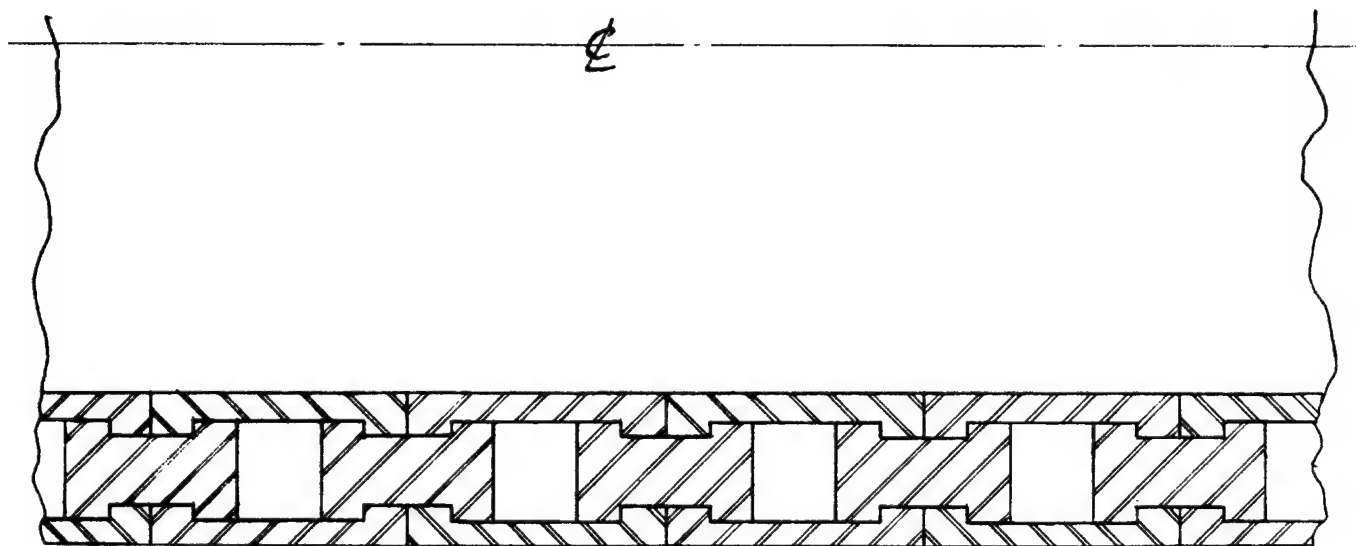
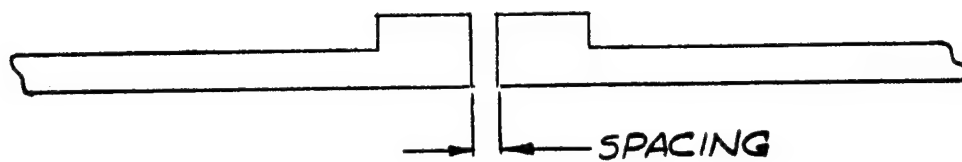


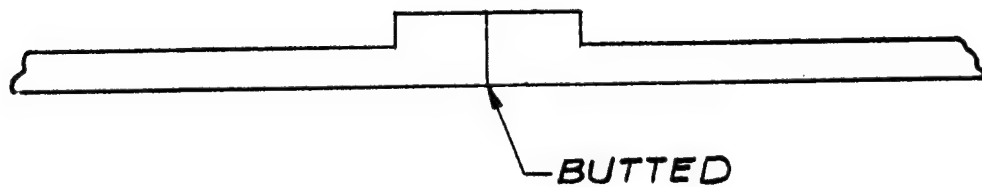
Figure 1
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CHANNEL END ARRANGEMENT



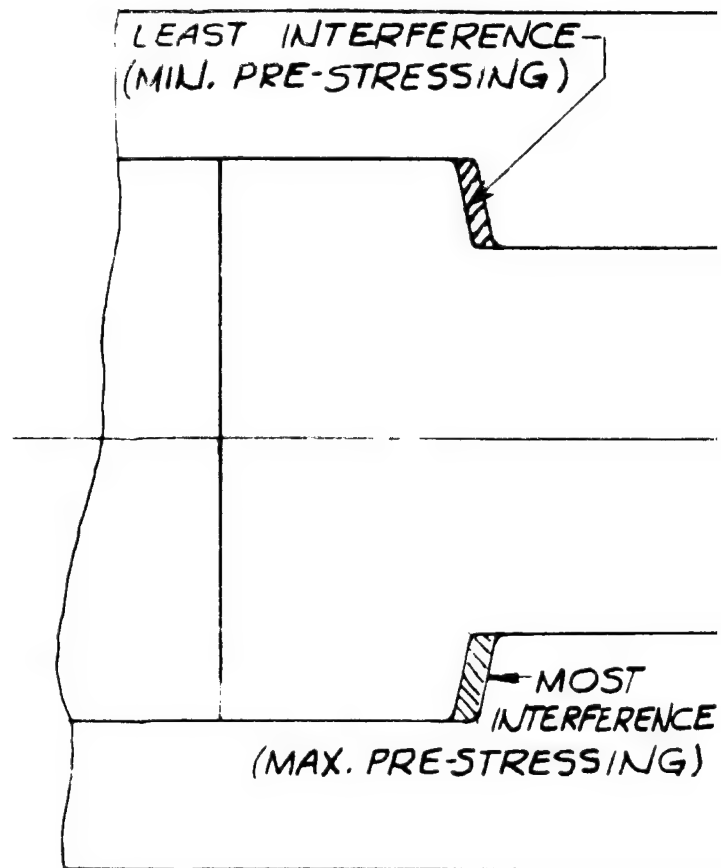
CHANNEL ENDS SPACED

(a)

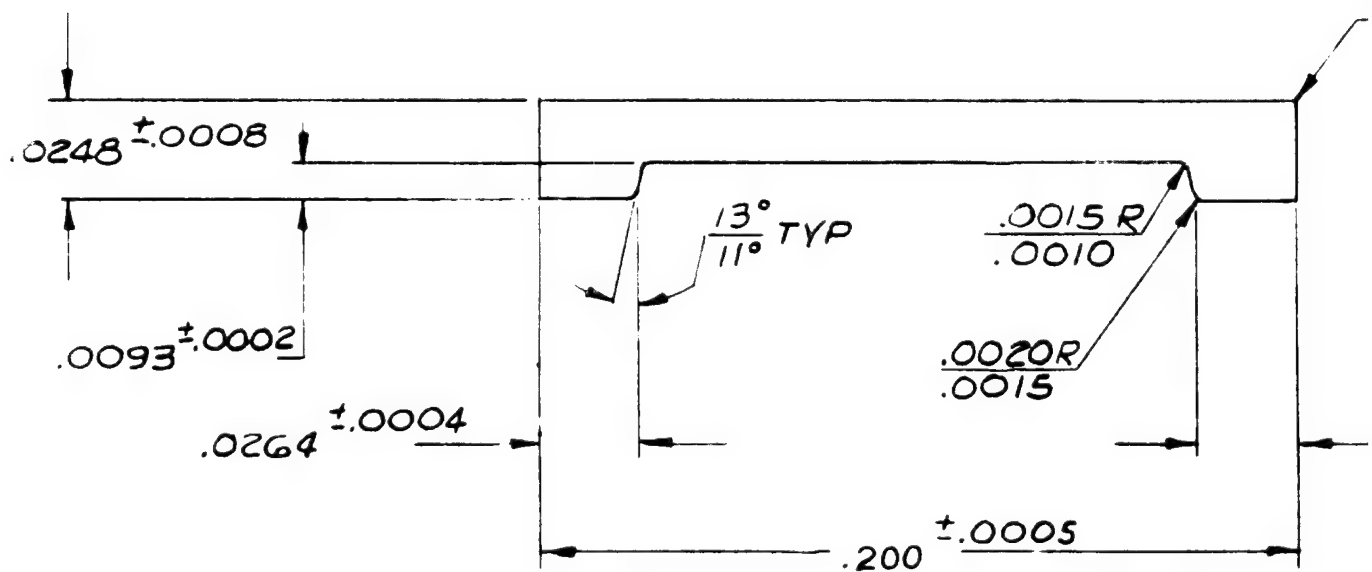


CHANNEL ENDS BUTTED

(b)



LOCKING W
SCALE

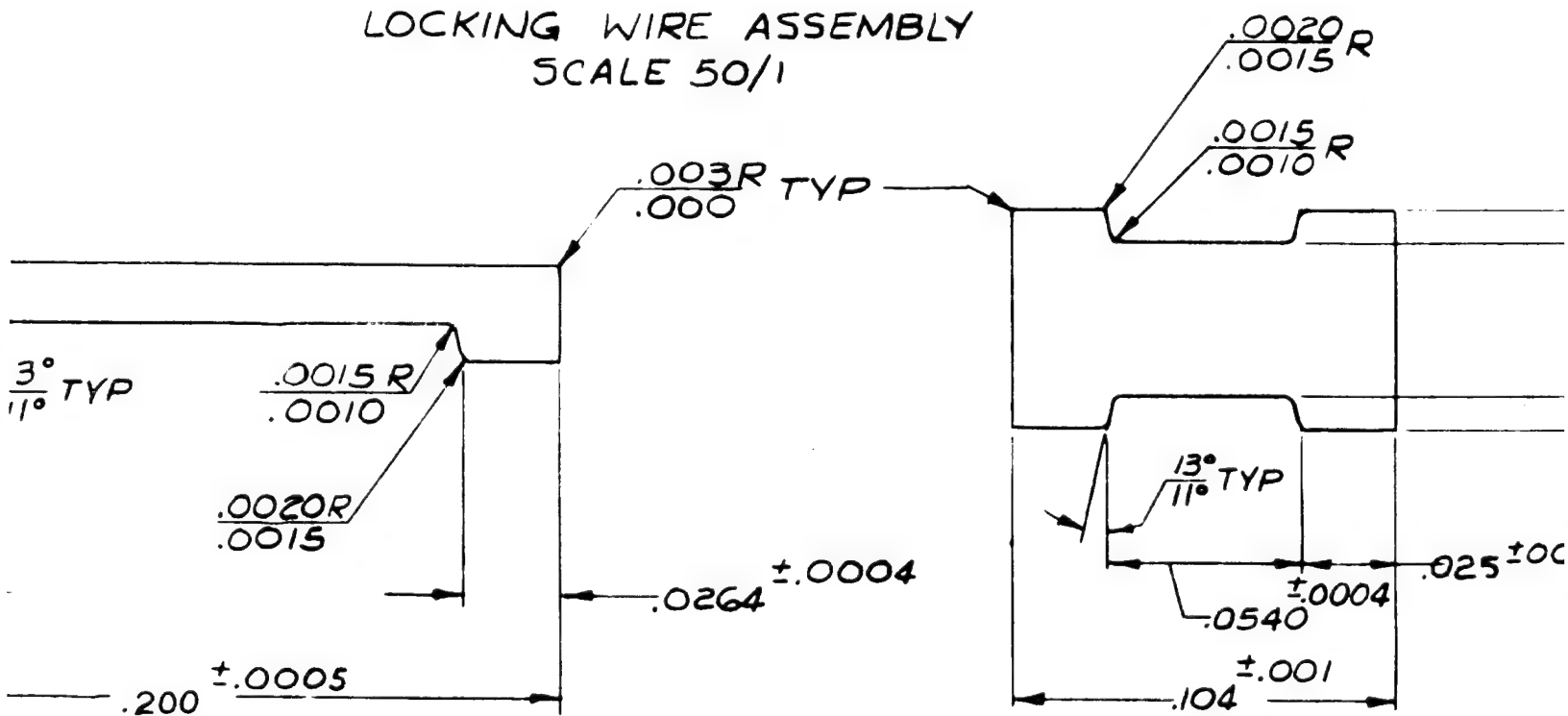


OUTER LOCKING WIRE DETAIL
SCALE 20/1

LEAST INTERFERENCE
(MIN. PRE-STRESSING)

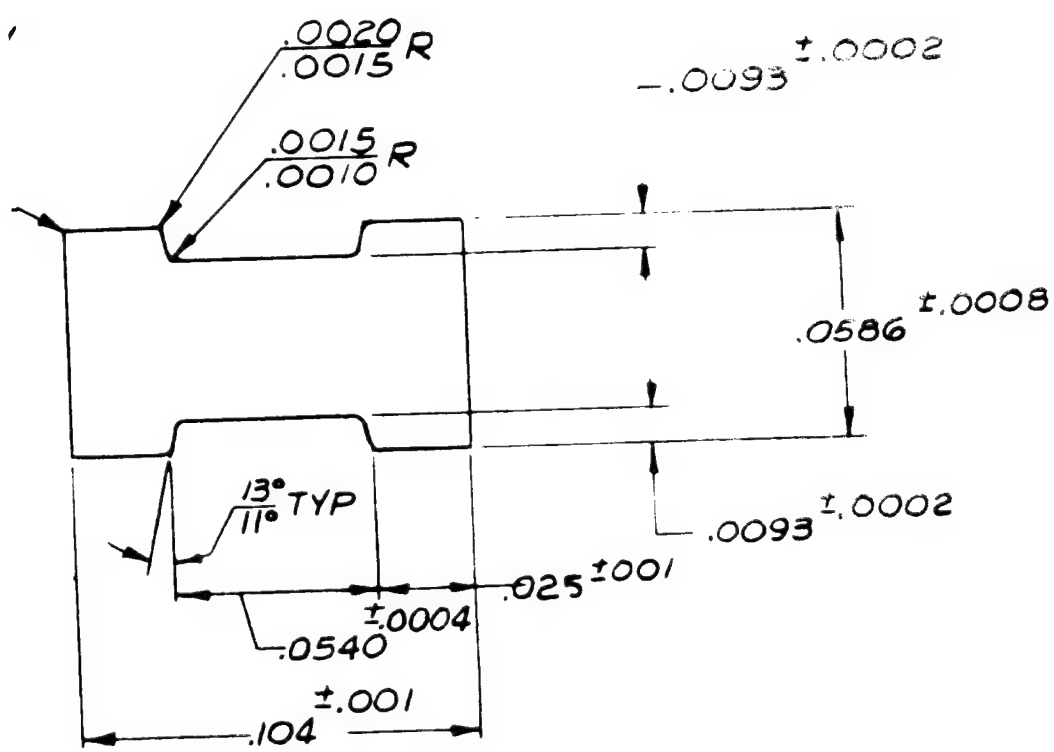
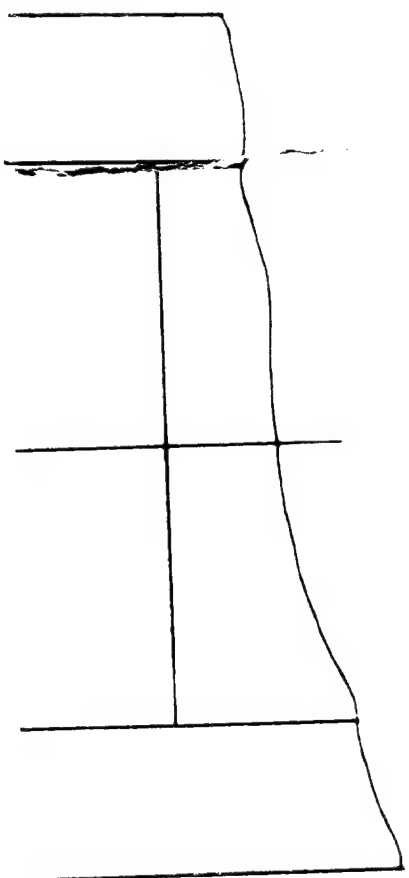
MOST
INTERFERENCE
(MAX. PRE-STRESSING)

LOCKING WIRE ASSEMBLY
SCALE 50/1



LOCKING WIRE DETAIL
SCALE 20/1

INNER LOCKING WIRE DETAIL
SCALE 20/1



ER LOCKING WIRE DETAIL
 SCALE 20/1

Figure 3
 13

BENDING STRESS - CHANNEL

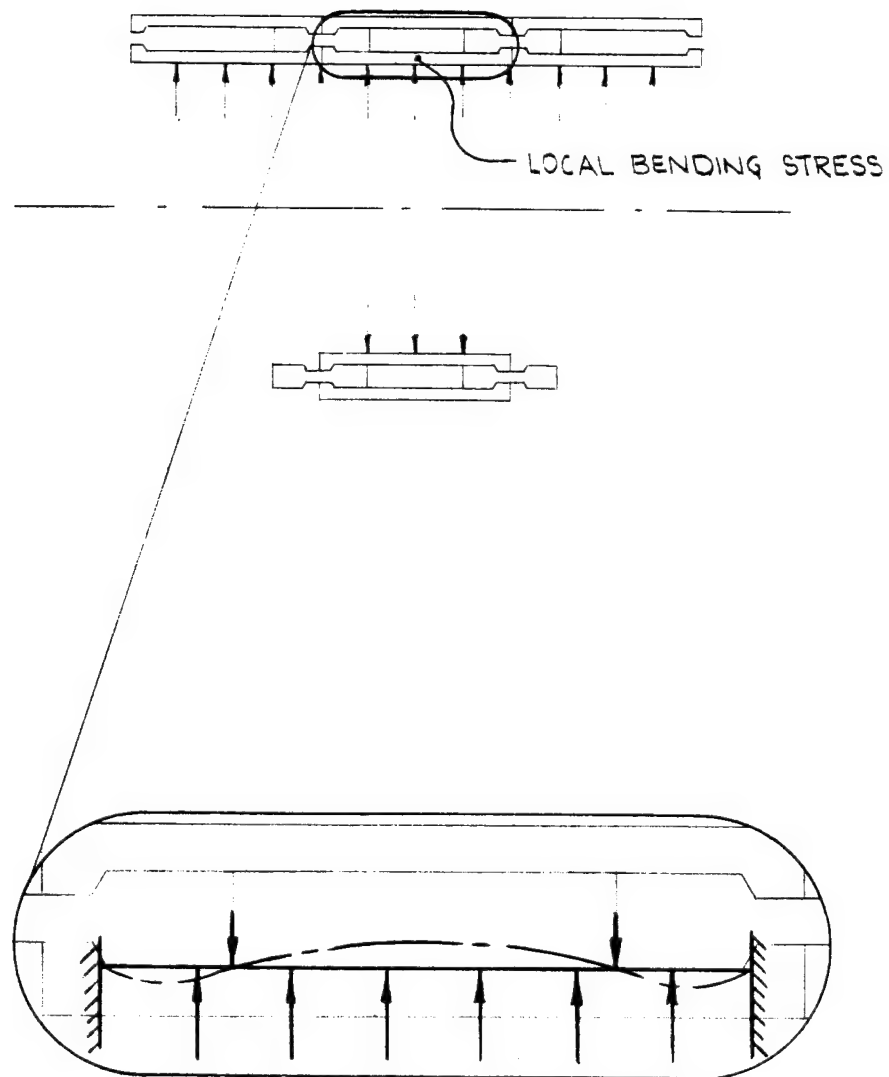
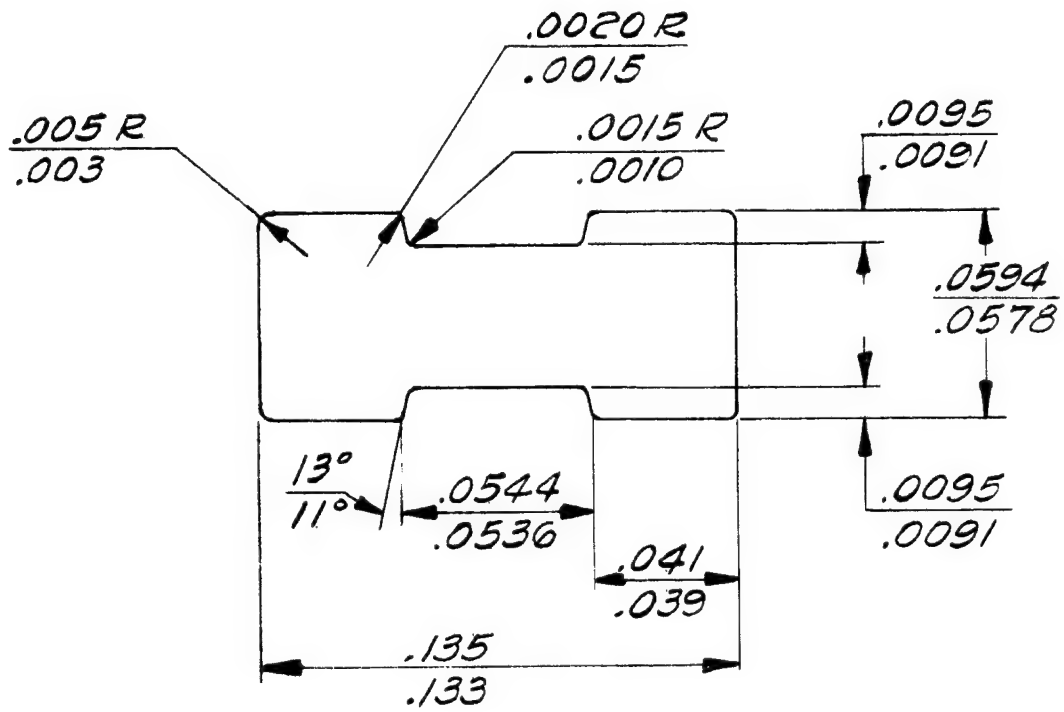
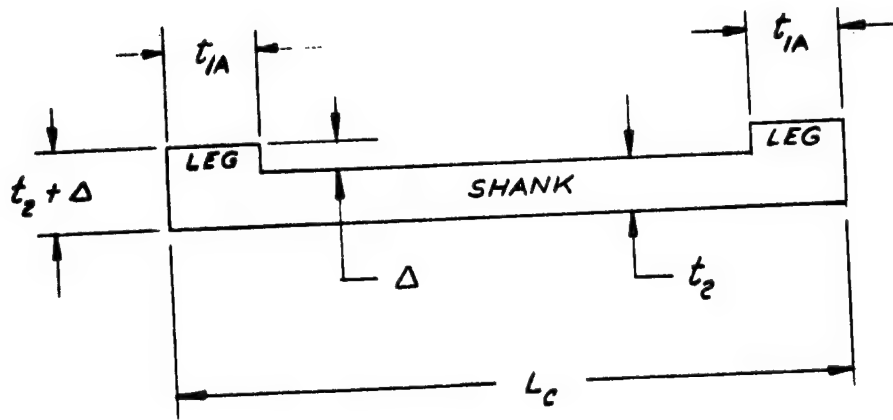


Figure 4
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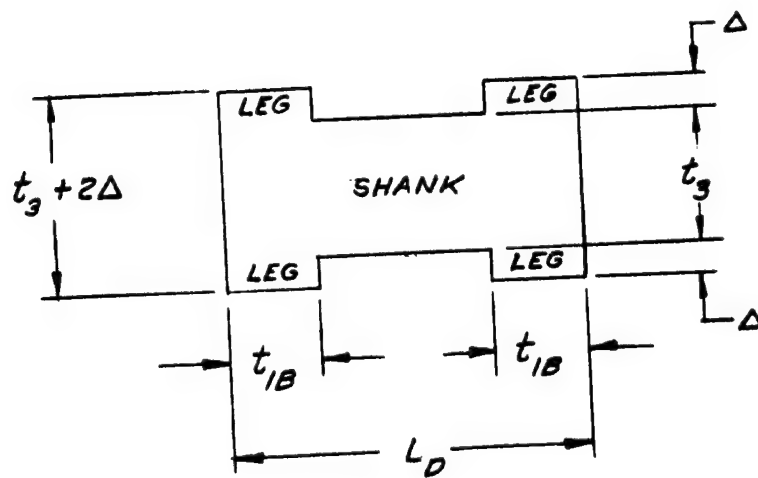


WIRE - I-BEAM

WIRE NOMENCLATURE



CHANNEL



DUMBBELL

STRESS ANALYSIS SUMMARY

Configuration	3 Layers Butted Channels
Wire Material	Titanium Alloy, B120VCA
Mechanical Properties (psi)	
Longitudinal	250,000
Transverse	250,000
Bearing	417,000
Shear	150,000
Dumbell Dimensions (in.)	
Length - L_D	0.104
Shank Thick. - t_3	0.040
Leg Thick. - t_{1B}	0.026
Spacing - S	0.093
Interlock - \triangle	0.0093
Channel Dimensions (in.)	
Length - L_C	0.197
Shank Thick. - t_2	0.0155
Leg Thick. - t_{1A}	0.026
Spacing - S	0
Interlock - \triangle	0.0093
Overall Vessel Thickness (in.)	0.089
Helix Angle	00-46.2'
Dumbell Stresses (psi)	
Hoop	250,000
Axial	250,000
Interlock Bearing	416,000
Channel Stresses (psi)	
Hoop	250,000
Axial	250,000
Leg Bending	0
Leg Shear	150,000
Shank Bending	0
Torsional Shear Stress (psi)	422

Fig. 7

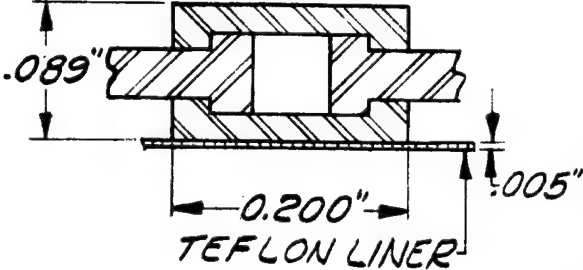
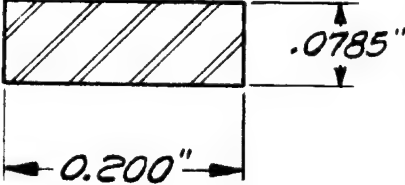
WEIGHT COMPARISON	
 <p>SEE FIGURE 3 FOR WIRE DIMENSIONS</p>	
TITANIUM AT 250,000 PSI Y.S.	TRICENT AT 200,000 PSI Y.S.
<p>CHANNEL (2) = .001269#</p> <p>DUMBELL (1) = .000897</p> <p>LINER = .000069</p> <hr/> <p>.002235#</p>	<p>SHELL = .00453#</p>
<p>WEIGHT SAVING OVER CYLINDRICAL = $\frac{.00453 - .002235}{.00453} = 50\%$</p> <p>SECTION OF TRICENT MOTOR</p>	

Figure 8
18

WIRE END ATTACHMENTS

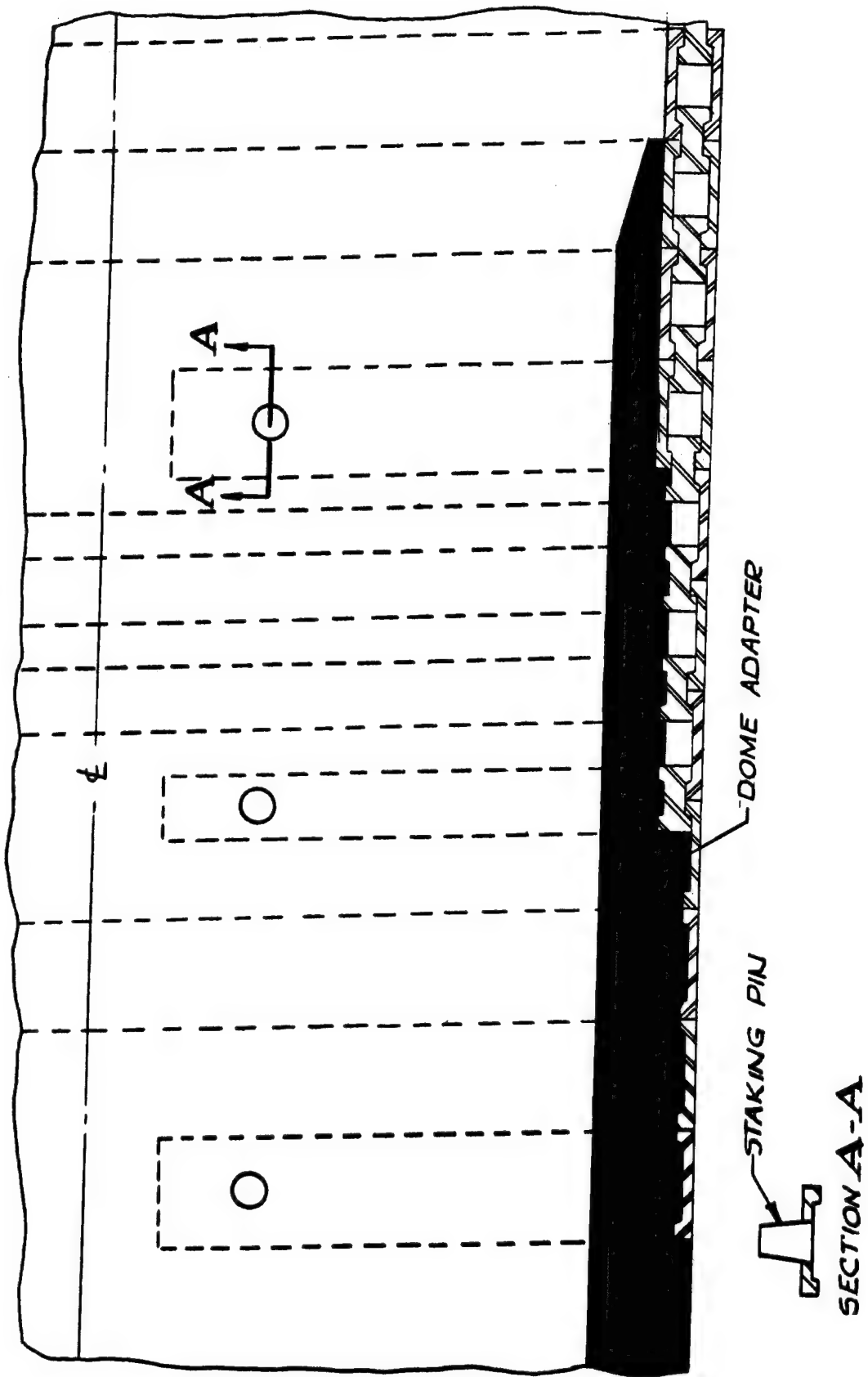


Figure 9
19

FREE BODY DIAGRAM
TORSIONAL SHEAR STRESSES

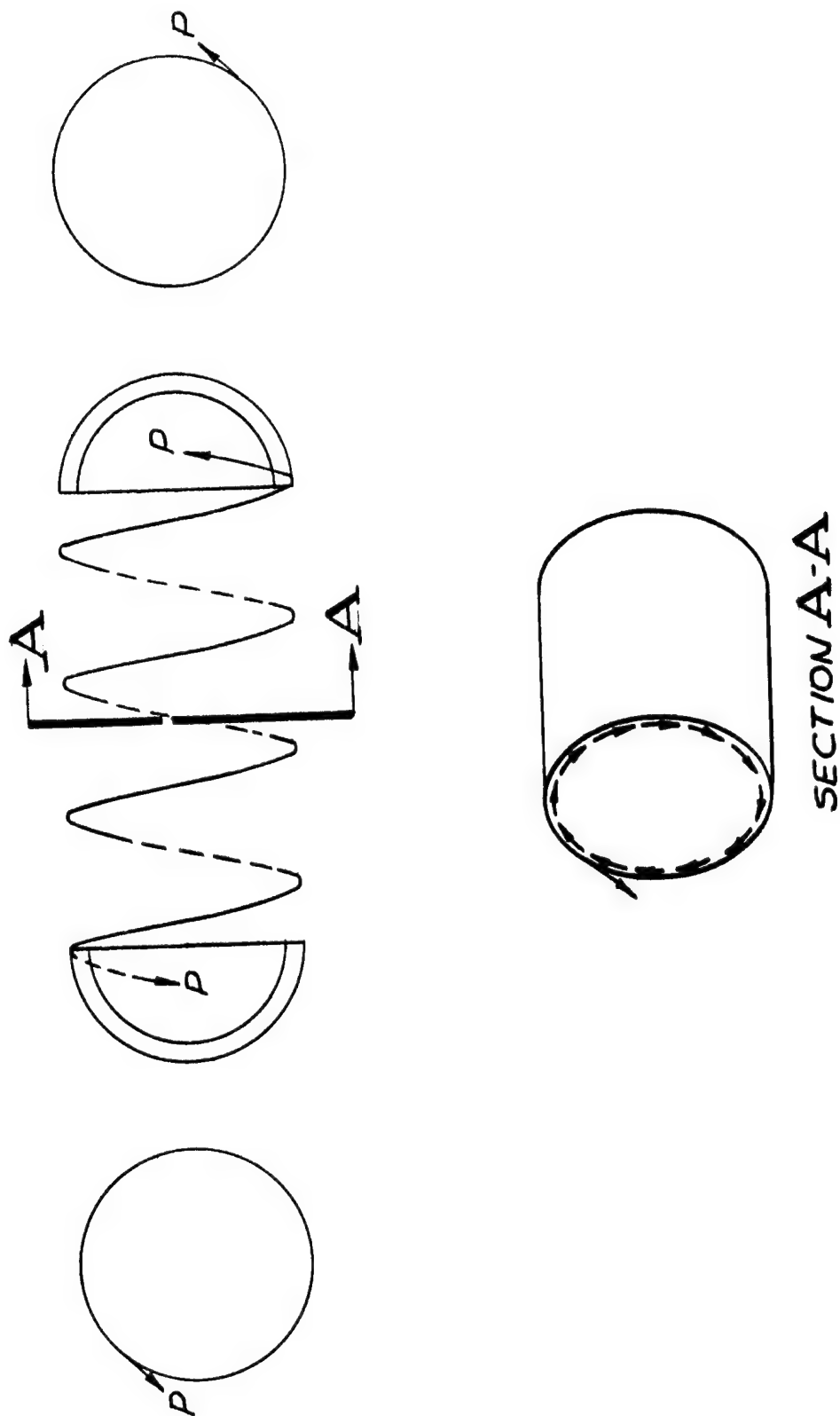
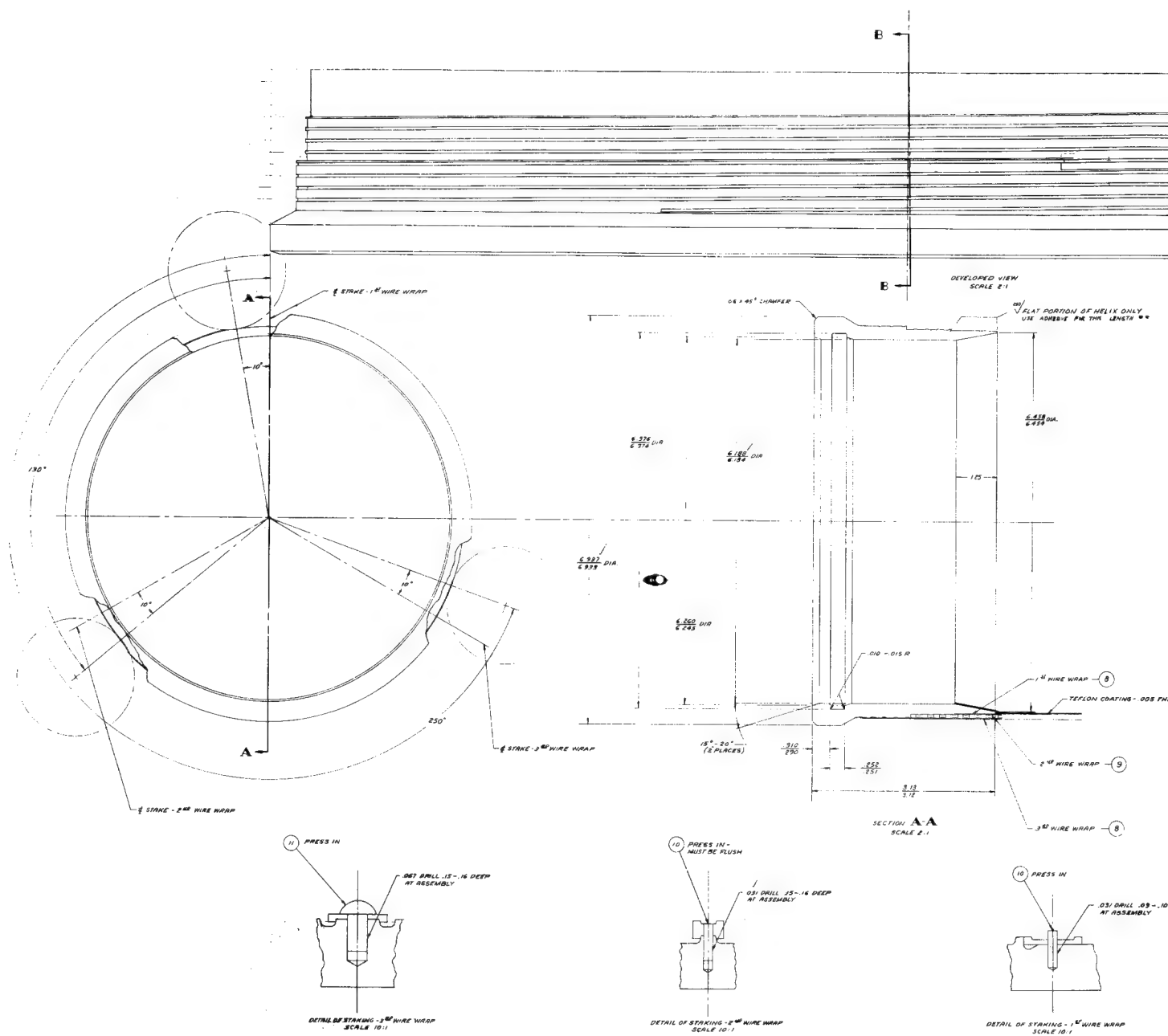
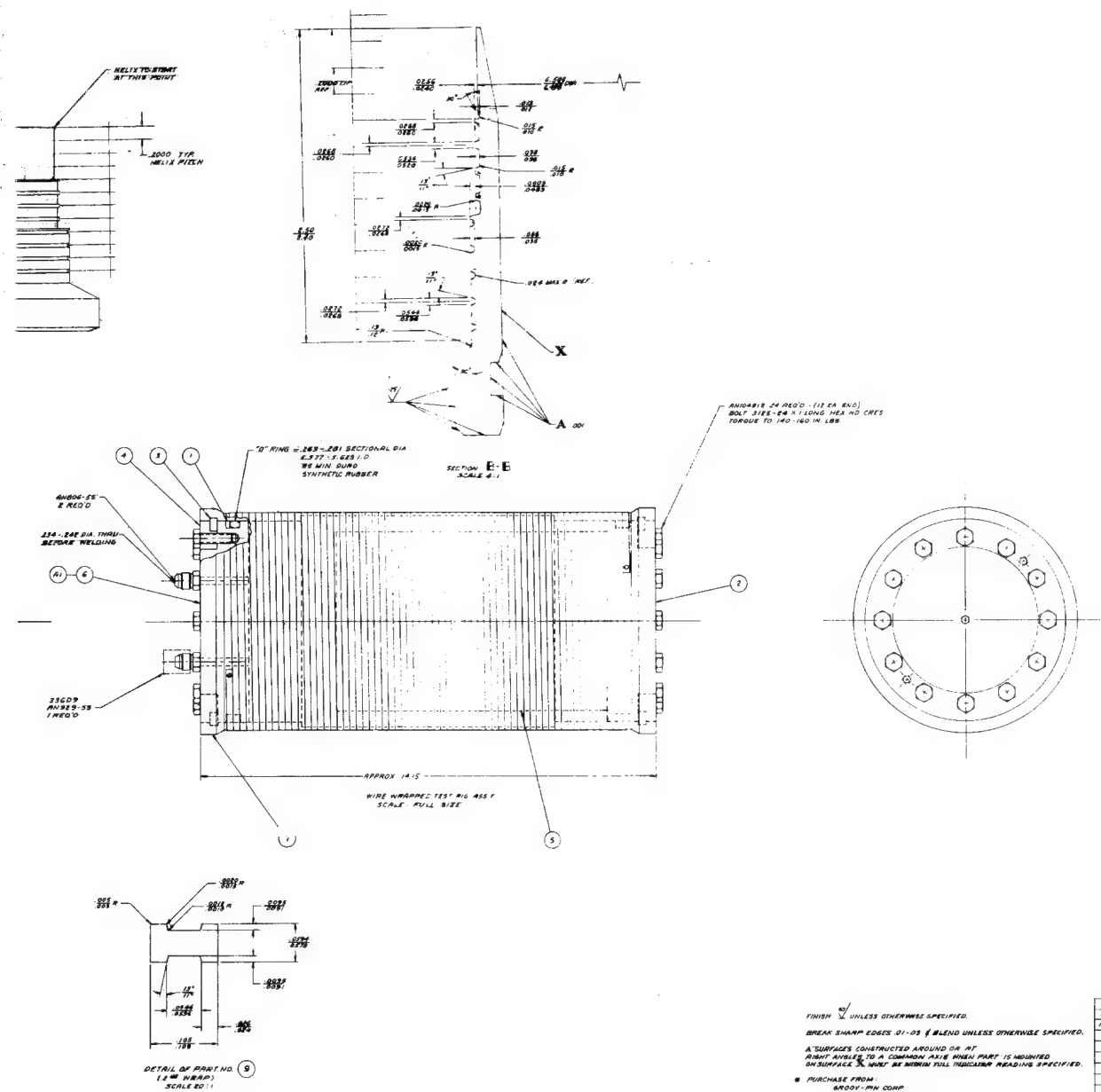


Figure 10
20





FINISH $\frac{1}{16}$ UNLESS OTHERWISE SPECIFIED.

BREAK SHARP EDGES 01-05 $\frac{1}{16}$ BLEND UNLESS OTHERWISE SPECIFIED.

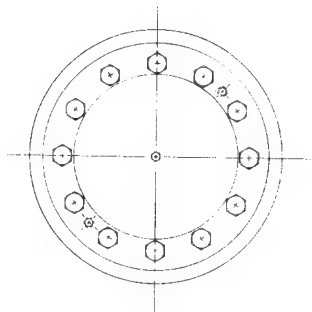
A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE $\frac{1}{16}$ MUST BE MOUNTED FULL INDICATION READING SPECIFIED.

B. PURCHASE FROM:
BROOKLYN COMP
1125 HENDRICKS CAUSEWAY
RIDGEFIELD, N.J.

C. MARBLETTE INC.
RESIN NO. 538
HARDENER NO. 57
9000 PSI

NO.	SECURITY	1. PLUGS & FITTINGS RES. V.	2. PRELIMINARY & LONG	3. PRELIMINARY & LONG
10		2. BUSHING PIN TYPE 1/2" DIA	3. BUSHING PIN TYPE 1/2" DIA	4. BUSHING PIN TYPE 1/2" DIA
11		3. WIRE - 1/2" DIA	4. WIRE - 1/2" DIA	5. WIRE - 1/2" DIA
12		4. WIRE - 1/2" DIA	5. WIRE - 1/2" DIA	6. WIRE - 1/2" DIA
13		5. WIRE - 1/2" DIA	6. WIRE - 1/2" DIA	7. WIRE - 1/2" DIA
14		6. WIRE - 1/2" DIA	7. WIRE - 1/2" DIA	8. WIRE - 1/2" DIA
15		7. WIRE - 1/2" DIA	8. WIRE - 1/2" DIA	9. WIRE - 1/2" DIA
16		8. WIRE - 1/2" DIA	9. WIRE - 1/2" DIA	10. WIRE - 1/2" DIA
17		9. WIRE - 1/2" DIA	10. WIRE - 1/2" DIA	11. WIRE - 1/2" DIA
18		10. WIRE - 1/2" DIA	11. WIRE - 1/2" DIA	12. WIRE - 1/2" DIA
19		11. WIRE - 1/2" DIA	12. WIRE - 1/2" DIA	13. WIRE - 1/2" DIA
20		12. WIRE - 1/2" DIA	13. WIRE - 1/2" DIA	14. WIRE - 1/2" DIA
21		13. WIRE - 1/2" DIA	14. WIRE - 1/2" DIA	15. WIRE - 1/2" DIA
22		14. WIRE - 1/2" DIA	15. WIRE - 1/2" DIA	16. WIRE - 1/2" DIA
23		15. WIRE - 1/2" DIA	16. WIRE - 1/2" DIA	17. WIRE - 1/2" DIA
24		16. WIRE - 1/2" DIA	17. WIRE - 1/2" DIA	18. WIRE - 1/2" DIA
25		17. WIRE - 1/2" DIA	18. WIRE - 1/2" DIA	19. WIRE - 1/2" DIA
26		18. WIRE - 1/2" DIA	19. WIRE - 1/2" DIA	20. WIRE - 1/2" DIA
27		19. WIRE - 1/2" DIA	20. WIRE - 1/2" DIA	21. WIRE - 1/2" DIA
28		20. WIRE - 1/2" DIA	21. WIRE - 1/2" DIA	22. WIRE - 1/2" DIA
29		21. WIRE - 1/2" DIA	22. WIRE - 1/2" DIA	23. WIRE - 1/2" DIA
30		22. WIRE - 1/2" DIA	23. WIRE - 1/2" DIA	24. WIRE - 1/2" DIA
31		23. WIRE - 1/2" DIA	24. WIRE - 1/2" DIA	25. WIRE - 1/2" DIA
32		24. WIRE - 1/2" DIA	25. WIRE - 1/2" DIA	26. WIRE - 1/2" DIA
33		25. WIRE - 1/2" DIA	26. WIRE - 1/2" DIA	27. WIRE - 1/2" DIA
34		26. WIRE - 1/2" DIA	27. WIRE - 1/2" DIA	28. WIRE - 1/2" DIA
35		27. WIRE - 1/2" DIA	28. WIRE - 1/2" DIA	29. WIRE - 1/2" DIA
36		28. WIRE - 1/2" DIA	29. WIRE - 1/2" DIA	30. WIRE - 1/2" DIA
37		29. WIRE - 1/2" DIA	30. WIRE - 1/2" DIA	31. WIRE - 1/2" DIA
38		30. WIRE - 1/2" DIA	31. WIRE - 1/2" DIA	32. WIRE - 1/2" DIA
39		31. WIRE - 1/2" DIA	32. WIRE - 1/2" DIA	33. WIRE - 1/2" DIA
40		32. WIRE - 1/2" DIA	33. WIRE - 1/2" DIA	34. WIRE - 1/2" DIA
41		33. WIRE - 1/2" DIA	34. WIRE - 1/2" DIA	35. WIRE - 1/2" DIA
42		34. WIRE - 1/2" DIA	35. WIRE - 1/2" DIA	36. WIRE - 1/2" DIA
43		35. WIRE - 1/2" DIA	36. WIRE - 1/2" DIA	37. WIRE - 1/2" DIA
44		36. WIRE - 1/2" DIA	37. WIRE - 1/2" DIA	38. WIRE - 1/2" DIA
45		37. WIRE - 1/2" DIA	38. WIRE - 1/2" DIA	39. WIRE - 1/2" DIA
46		38. WIRE - 1/2" DIA	39. WIRE - 1/2" DIA	40. WIRE - 1/2" DIA
47		39. WIRE - 1/2" DIA	40. WIRE - 1/2" DIA	41. WIRE - 1/2" DIA
48		40. WIRE - 1/2" DIA	41. WIRE - 1/2" DIA	42. WIRE - 1/2" DIA
49		41. WIRE - 1/2" DIA	42. WIRE - 1/2" DIA	43. WIRE - 1/2" DIA
50		42. WIRE - 1/2" DIA	43. WIRE - 1/2" DIA	44. WIRE - 1/2" DIA
51		43. WIRE - 1/2" DIA	44. WIRE - 1/2" DIA	45. WIRE - 1/2" DIA
52		44. WIRE - 1/2" DIA	45. WIRE - 1/2" DIA	46. WIRE - 1/2" DIA
53		45. WIRE - 1/2" DIA	46. WIRE - 1/2" DIA	47. WIRE - 1/2" DIA
54		46. WIRE - 1/2" DIA	47. WIRE - 1/2" DIA	48. WIRE - 1/2" DIA
55		47. WIRE - 1/2" DIA	48. WIRE - 1/2" DIA	49. WIRE - 1/2" DIA
56		48. WIRE - 1/2" DIA	49. WIRE - 1/2" DIA	50. WIRE - 1/2" DIA
57		49. WIRE - 1/2" DIA	50. WIRE - 1/2" DIA	51. WIRE - 1/2" DIA
58		50. WIRE - 1/2" DIA	51. WIRE - 1/2" DIA	52. WIRE - 1/2" DIA
59		51. WIRE - 1/2" DIA	52. WIRE - 1/2" DIA	53. WIRE - 1/2" DIA
60		52. WIRE - 1/2" DIA	53. WIRE - 1/2" DIA	54. WIRE - 1/2" DIA
61		53. WIRE - 1/2" DIA	54. WIRE - 1/2" DIA	55. WIRE - 1/2" DIA
62		54. WIRE - 1/2" DIA	55. WIRE - 1/2" DIA	56. WIRE - 1/2" DIA
63		55. WIRE - 1/2" DIA	56. WIRE - 1/2" DIA	57. WIRE - 1/2" DIA
64		56. WIRE - 1/2" DIA	57. WIRE - 1/2" DIA	58. WIRE - 1/2" DIA
65		57. WIRE - 1/2" DIA	58. WIRE - 1/2" DIA	59. WIRE - 1/2" DIA
66		58. WIRE - 1/2" DIA	59. WIRE - 1/2" DIA	60. WIRE - 1/2" DIA
67		59. WIRE - 1/2" DIA	60. WIRE - 1/2" DIA	61. WIRE - 1/2" DIA
68		60. WIRE - 1/2" DIA	61. WIRE - 1/2" DIA	62. WIRE - 1/2" DIA
69		61. WIRE - 1/2" DIA	62. WIRE - 1/2" DIA	63. WIRE - 1/2" DIA
70		62. WIRE - 1/2" DIA	63. WIRE - 1/2" DIA	64. WIRE - 1/2" DIA
71		63. WIRE - 1/2" DIA	64. WIRE - 1/2" DIA	65. WIRE - 1/2" DIA
72		64. WIRE - 1/2" DIA	65. WIRE - 1/2" DIA	66. WIRE - 1/2" DIA
73		65. WIRE - 1/2" DIA	66. WIRE - 1/2" DIA	67. WIRE - 1/2" DIA
74		66. WIRE - 1/2" DIA	67. WIRE - 1/2" DIA	68. WIRE - 1/2" DIA
75		67. WIRE - 1/2" DIA	68. WIRE - 1/2" DIA	69. WIRE - 1/2" DIA
76		68. WIRE - 1/2" DIA	69. WIRE - 1/2" DIA	70. WIRE - 1/2" DIA
77		69. WIRE - 1/2" DIA	70. WIRE - 1/2" DIA	71. WIRE - 1/2" DIA
78		70. WIRE - 1/2" DIA	71. WIRE - 1/2" DIA	72. WIRE - 1/2" DIA
79		71. WIRE - 1/2" DIA	72. WIRE - 1/2" DIA	73. WIRE - 1/2" DIA
80		72. WIRE - 1/2" DIA	73. WIRE - 1/2" DIA	74. WIRE - 1/2" DIA
81		73. WIRE - 1/2" DIA	74. WIRE - 1/2" DIA	75. WIRE - 1/2" DIA
82		74. WIRE - 1/2" DIA	75. WIRE - 1/2" DIA	76. WIRE - 1/2" DIA
83		75. WIRE - 1/2" DIA	76. WIRE - 1/2" DIA	77. WIRE - 1/2" DIA
84		76. WIRE - 1/2" DIA	77. WIRE - 1/2" DIA	78. WIRE - 1/2" DIA
85		77. WIRE - 1/2" DIA	78. WIRE - 1/2" DIA	79. WIRE - 1/2" DIA
86		78. WIRE - 1/2" DIA	79. WIRE - 1/2" DIA	80. WIRE - 1/2" DIA
87		79. WIRE - 1/2" DIA	80. WIRE - 1/2" DIA	81. WIRE - 1/2" DIA
88		80. WIRE - 1/2" DIA	81. WIRE - 1/2" DIA	82. WIRE - 1/2" DIA
89		81. WIRE - 1/2" DIA	82. WIRE - 1/2" DIA	83. WIRE - 1/2" DIA
90		82. WIRE - 1/2" DIA	83. WIRE - 1/2" DIA	84. WIRE - 1/2" DIA
91		83. WIRE - 1/2" DIA	84. WIRE - 1/2" DIA	85. WIRE - 1/2" DIA
92		84. WIRE - 1/2" DIA	85. WIRE - 1/2" DIA	86. WIRE - 1/2" DIA
93		85. WIRE - 1/2" DIA	86. WIRE - 1/2" DIA	87. WIRE - 1/2" DIA
94		86. WIRE - 1/2" DIA	87. WIRE - 1/2" DIA	88. WIRE - 1/2" DIA
95		87. WIRE - 1/2" DIA	88. WIRE - 1/2" DIA	89. WIRE - 1/2" DIA
96		88. WIRE - 1/2" DIA	89. WIRE - 1/2" DIA	90. WIRE - 1/2" DIA
97		89. WIRE - 1/2" DIA	90. WIRE - 1/2" DIA	91. WIRE - 1/2" DIA
98		90. WIRE - 1/2" DIA	91. WIRE - 1/2" DIA	92. WIRE - 1/2" DIA
99		91. WIRE - 1/2" DIA	92. WIRE - 1/2" DIA	93. WIRE - 1/2" DIA
100		92. WIRE - 1/2" DIA	93. WIRE - 1/2" DIA	94. WIRE - 1/2" DIA

Figure 11
21



FINISH ☒ UNLESS OTHERWISE SPECIFIED.

BREAK SHOWN EDGES 01-03 ☒ BLEND UNLESS OTHERWISE SPECIFIED.

ALL SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE ☒ MUST BE WITHIN TOLERANCE READING SPECIFIED.

• PURCHASE FROM:
8505 - 7th CORP
1125 NEWPORTS CAUSEWAY
RIDGEFIELD, N.J.

• MARBLETTE INC
KEITH RD. 332
WARRNER RD. 37
(Phone) - 6500 PSI

41	12/26/68	1	PLUG & FITTING ONLY				
42		2	WOUND ON DRIVE SHAFT NO. 3		DRIVE SHAFT	1/2 LBS	
43		3	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
44		4	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
45		5	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
46		6	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
47		7	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
48		8	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
49		9	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
50		10	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
51		11	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
52		12	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
53		13	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
54		14	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
55		15	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
56		16	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
57		17	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
58		18	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
59		19	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
60		20	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
61		21	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
62		22	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
63		23	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
64		24	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1/2 LBS		
65		25	WOUND ON DRIVE SHAFT NO. 3	DRIVE SHAFT	1		

CALL OR IMMEDIATELY

FOR MANAGER

DATE: 12-28-68

TIME: 1:00 PM

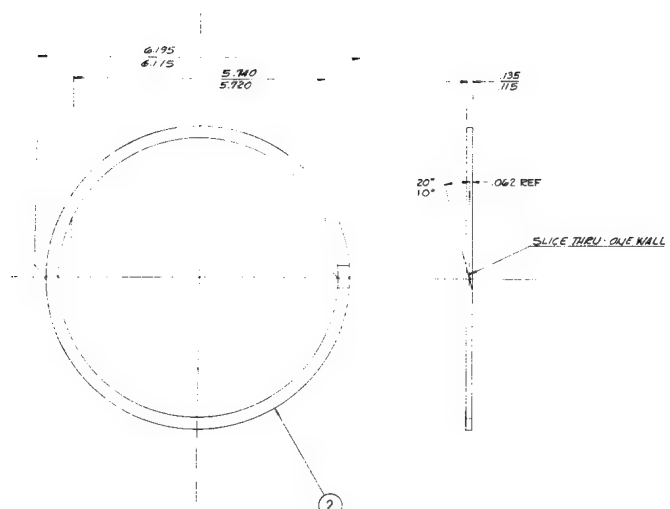
BY: J. L. HARRIS

TEST RIG -

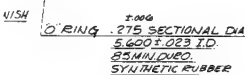
WINDS WRAPPED

\$125.00

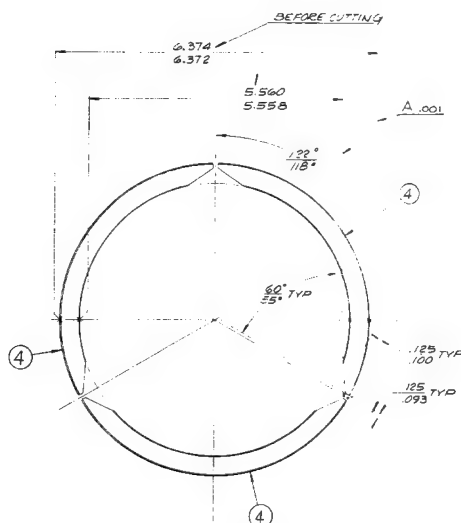
Figure 11
21



2 DR. TO DIM SHOWN
25.24 TAP TO DIM SHOWN
TAPPED HOLES EQ. SPACED
WIN. 0.10 OF T.P. ON 5/25 (BOS. R)
LT. CIRCLE (PLUG ONLY)



DETAIL A

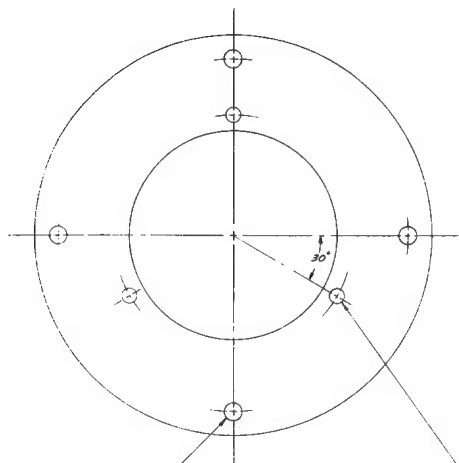


A1	A29955	1	PLUG & FITTING ASSEMBLY	20-2000-2000 40" X 56" X 6"
A1	A180696	1	CAP ASSURANCE PRESS SEAL	20-2000-2000 40" X 56" X 6"
		2	PLUG-FLARED TUBE	20-2000-2000 40" X 56" X 6"
	A1	1	PLUG - INLET	20-2000-2000 40" X 56" X 6"
		1	CYLINDER	20-2000-2000 40" X 56" X 6"
8	W10485	24	BOAT HEX HD. 3/25 24" X 1/2" CEEB	20-2000-2000 40" X 56" X 6"
		2	ONE SMOOD. 25 24" X 1/2" CEEB	20-2000-2000 40" X 56" X 6"
		2	RATE RESTRICTOR	20-2000-2000 40" X 56" X 6"
		1	RING - SEGMENT	20-2000-2000 40" X 56" X 6"
		1	PLUG - PLAIN	20-2000-2000 40" X 56" X 6"
		2	RING BACKUP - LEATHER	20-2000-2000 40" X 56" X 6"
		2	SPECIMEN	20-2000-2000 40" X 56" X 6"

125
FINISH ∇ UNLESS OTHERWISE
BREAK SHARP EDGES
INDICATED.
A SURFACES CONSTRUCTED
RIGHT ANGLES TO A CENTERLINE
WITHIN FULL INDICATION

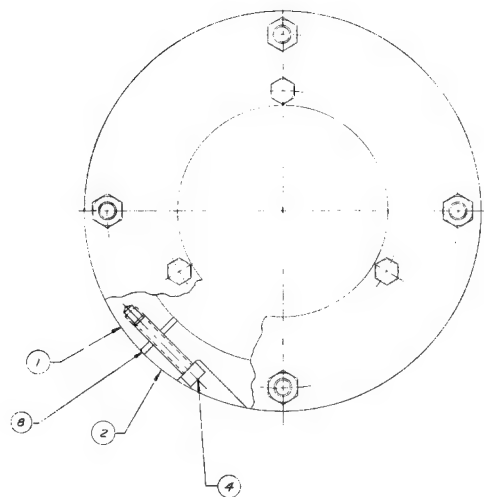
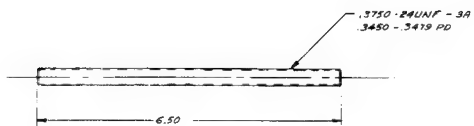
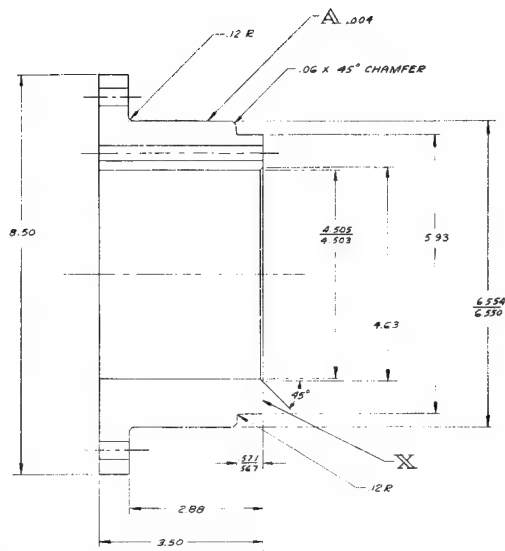
GIRTH WELD
-REDESIGN

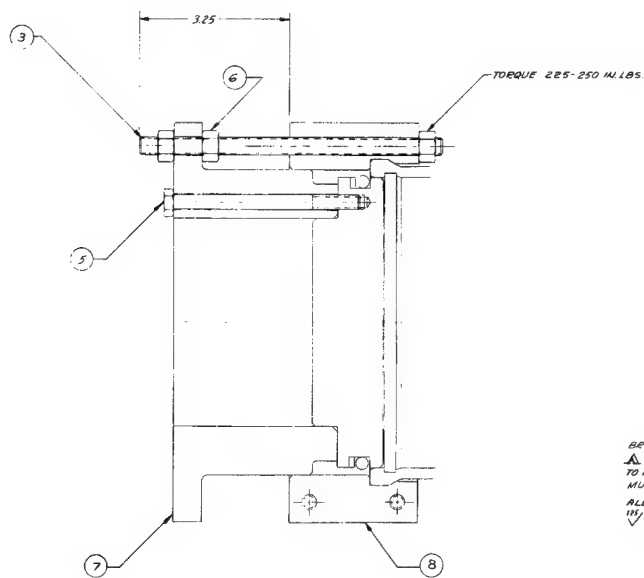
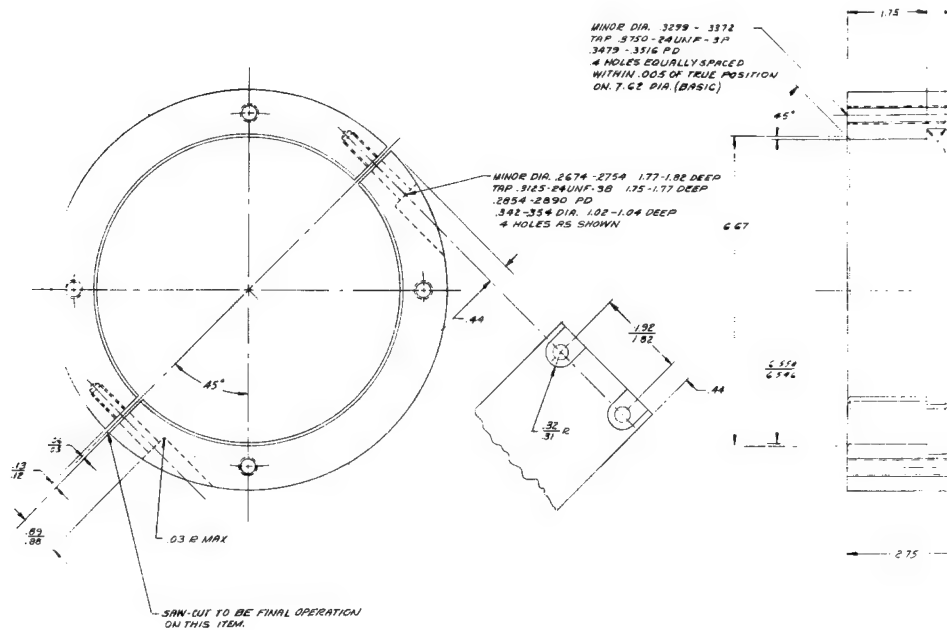
Figure 12
22



.404 - .416 DIA THRU
4 HOLES EQUALLY SPACED
WITHIN .005 OF TRUE POSITION
ON 7.62 DIA (BASIC)

.342 - .354 DIA THRU
3 HOLES EQUALLY SPACED
WITHIN .005 OF TRUE POSITION
ON 5.125 DIA (BASIC)





BREAK SHARP EDGES .01 - .02 & BLEND
A SURFACES CONSTRUCTED AROUND
TO A COMMON AXIS WHEN PART IS NOT
MUST BE WITHIN FULL INDICATED REAR
ALL NOTES APPLY UNLESS OTHERWISE
105/
✓ ALL OVER

FREEBODY DIAGRAM

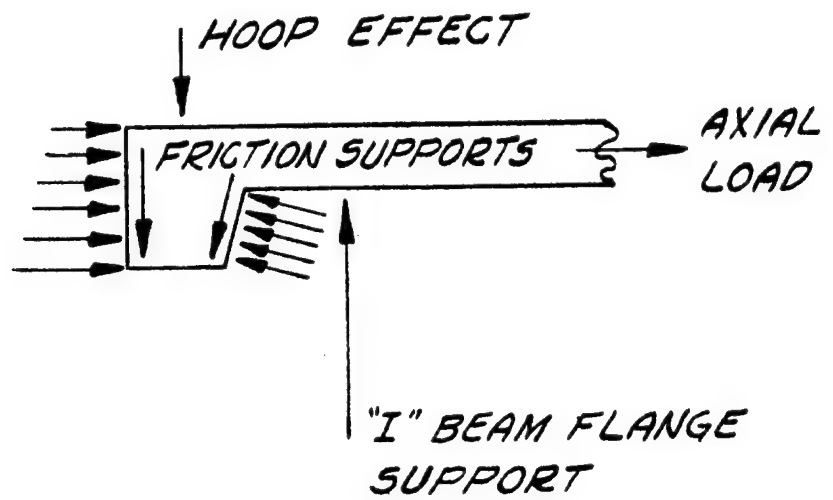
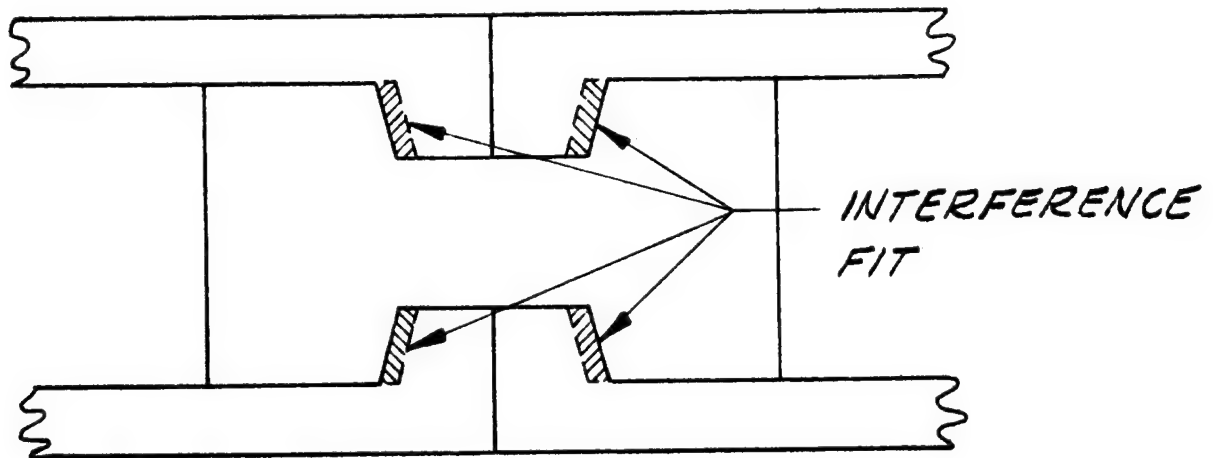
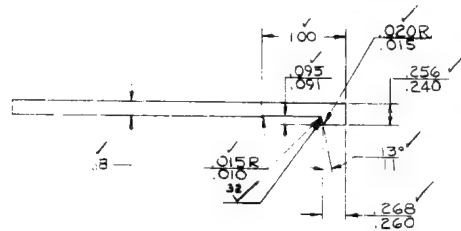
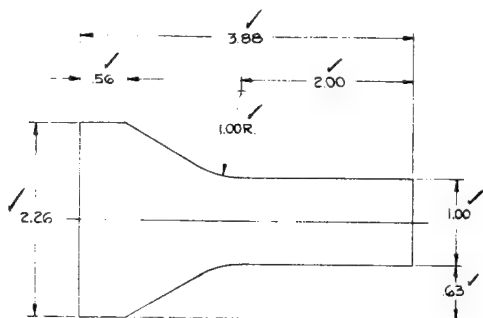
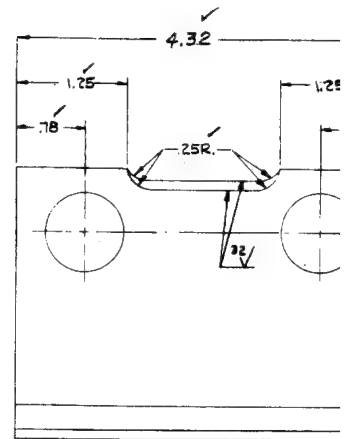
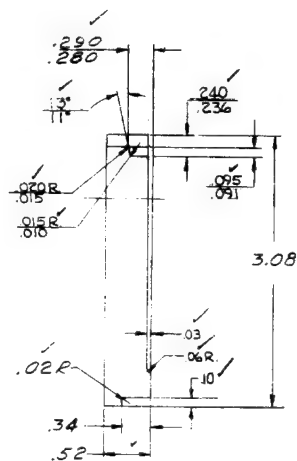


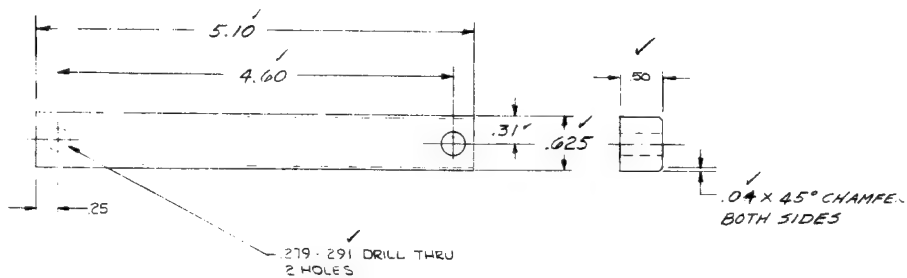
Figure 14
24



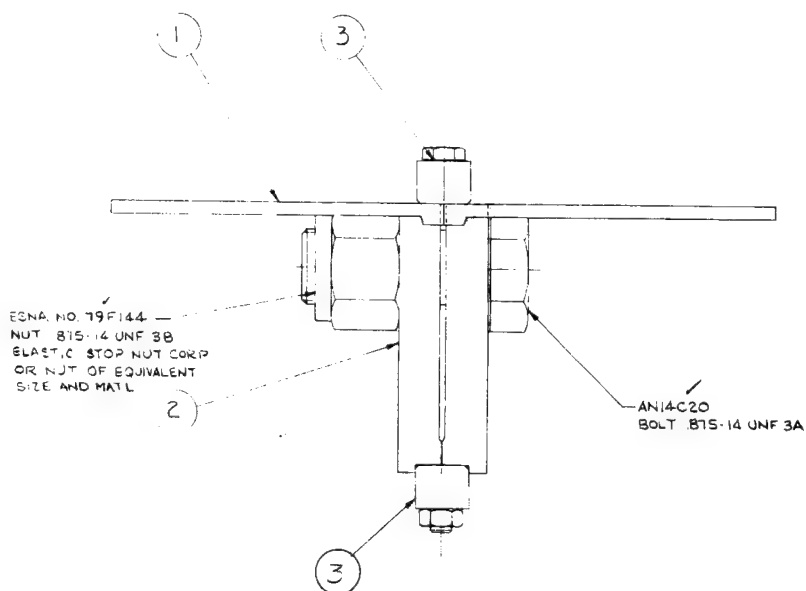
ITEM NO. 1



ITEM NO. 2



ITEM NO. 3

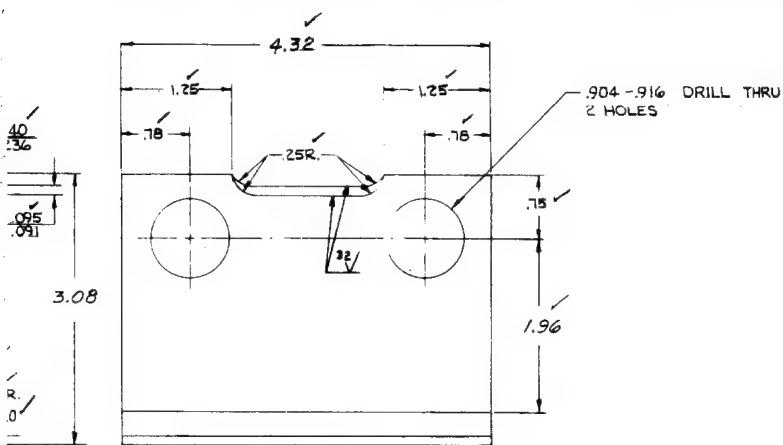


ESNA NO. 79F144 —
NUT .815-14 UNF 3B
ELASTIC STOP NUT CORP
OR NUT OF EQUIVALENT
SIZE AND MAT'L

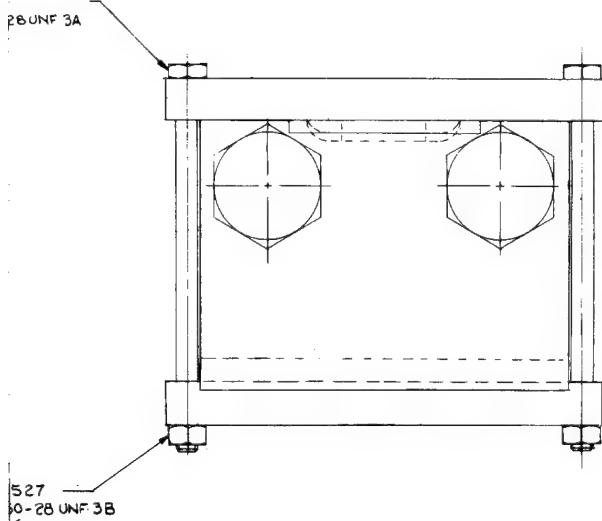
AN14C20
BOLT .815-14 UNF 3A


AN4C42
BOLT .250-28 UNF 3A

AN121527
NUT .250-28 UNF 3B



ITEM NO. 2



FINISH 
 BREAK SHARP EDGES
 .005-.015 APPROX R
 FINISHED DIM. $\pm .010$
 ALL ANGLES $\pm 2^\circ$
 ALL NOTES APPLY
 UNLESS OTHERWISE SPECIFIED

AN14220	2	BOLT-.875-14 UNF 3A 2 3/4" LENGTH
AN14220	2	NUT-.875-14 UNF 3B (SEE NOTE)
AN4C4Z	2	BLOT-.250-28 UNF-3A 4 3/4" LENGTH
AN121527	2	NUT-.250-28 UNF 3B
3	2	PLATE - SPECIMEN CLAMP
2	2	CLAMP - I-BEAM
1	2	SPECIMEN-CHANNEL 10/1 WIRE SIZE
PART NO. ASSY. PART NO. PART NO. PART NO. ADD REFERENCE DRAWING		
SCALE FULL JOB NUMBER 650032 10-25-60 10-27-60		
CURTISS INTER-LOCKING TITANIUM WIRE CASE - CHANNEL & I-BEAM JOINT RIG		

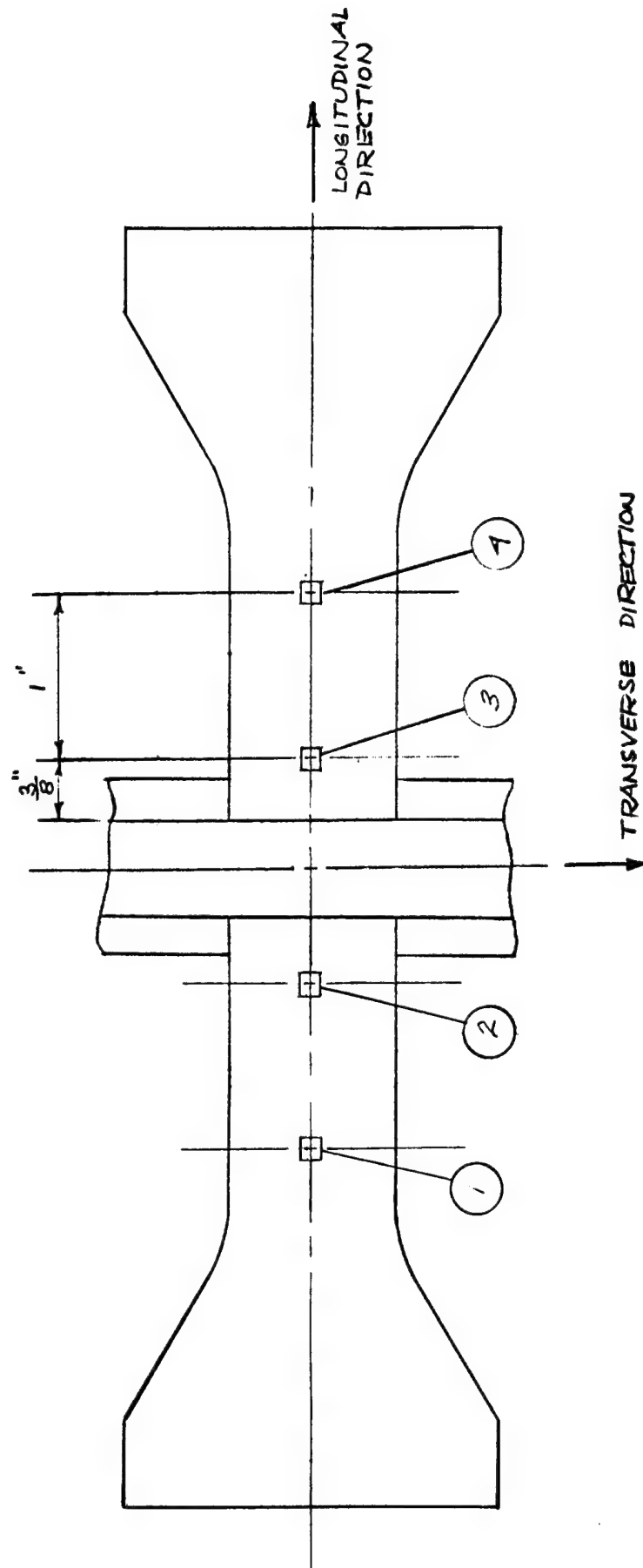
REVISIONS			
CHG LTR	DESCRIPTION	DATE	ENGRS.

LS 25810

Figure 15

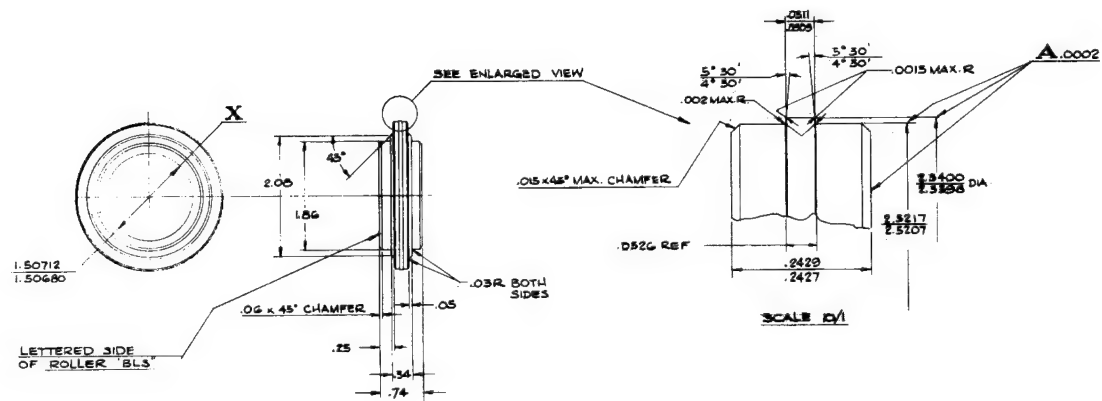
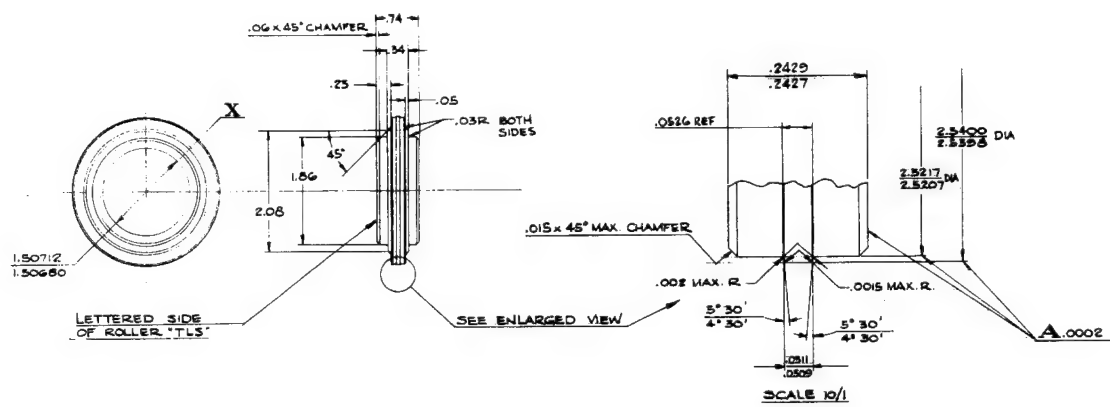
WIRE WRAP TEST FIXTURE

INSTRUMENTATION LAYOUT



NOTE :
ALL GAGES TO BE SR-4 A-18

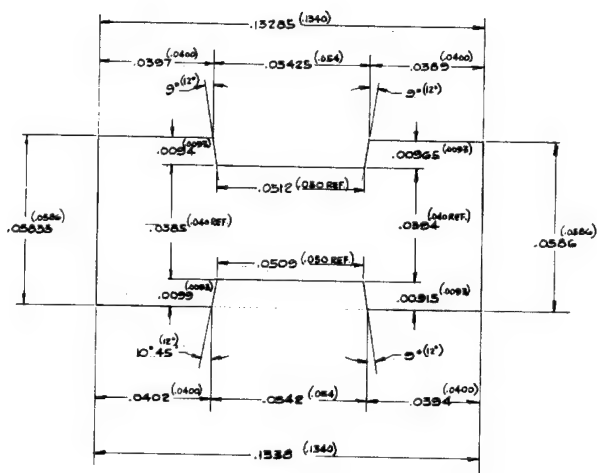
Figure 16
26



(.0586)
.05835

A.0002

A.0002



DIMENSIONS OF WIRE SAMPLE MADE
WITH ROLLERS SHOWN AT LEFT
(AVERAGE OF 2 SAMPLES)
DESIRED DIMENSIONS GIVEN IN PARENTHESES
SCALE 80X

UNLESS OTHERWISE SPECIFIED

ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.	2
	ADD		REFERENCE	CANCEL	
SCALE 1/1					
JOB NUMBER					
CURTIS-WRIGHT CO.					
WRIGHT AERONAUTICAL CO.					
WOODBRIDGE, NEW JERSEY, U.S.A.					

LS25754

SH. 4

UNLESS OTHERWISE SPECIFIED

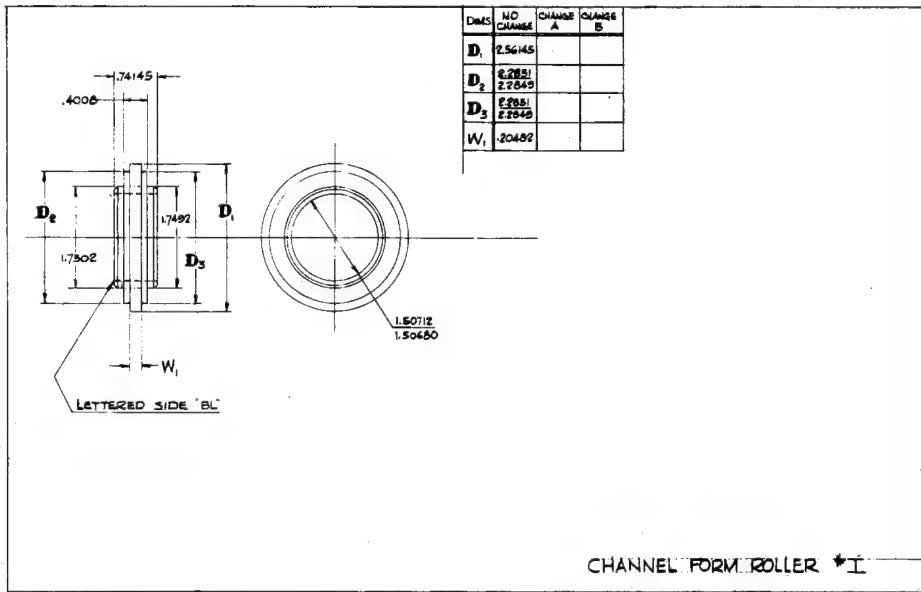
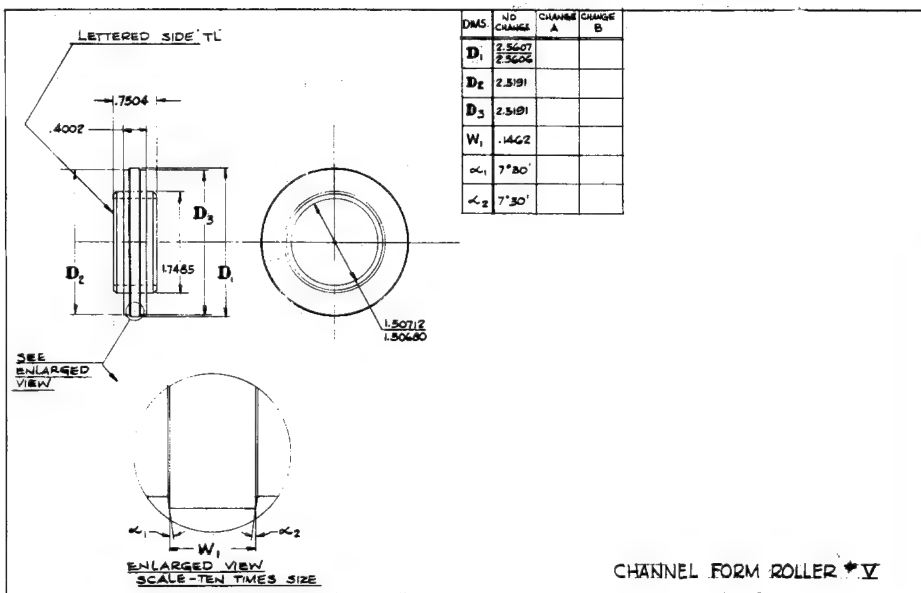
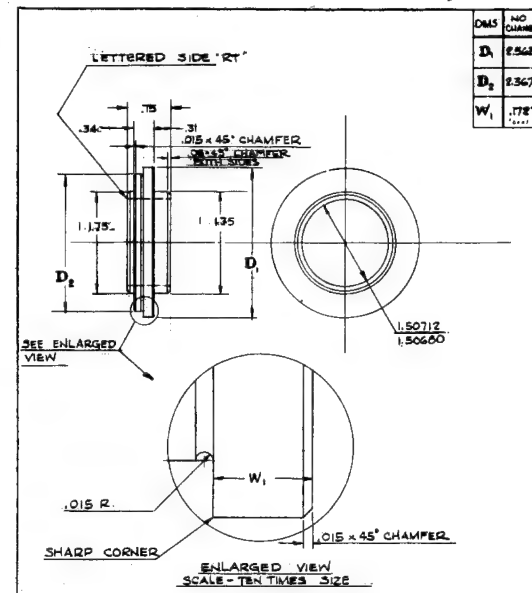
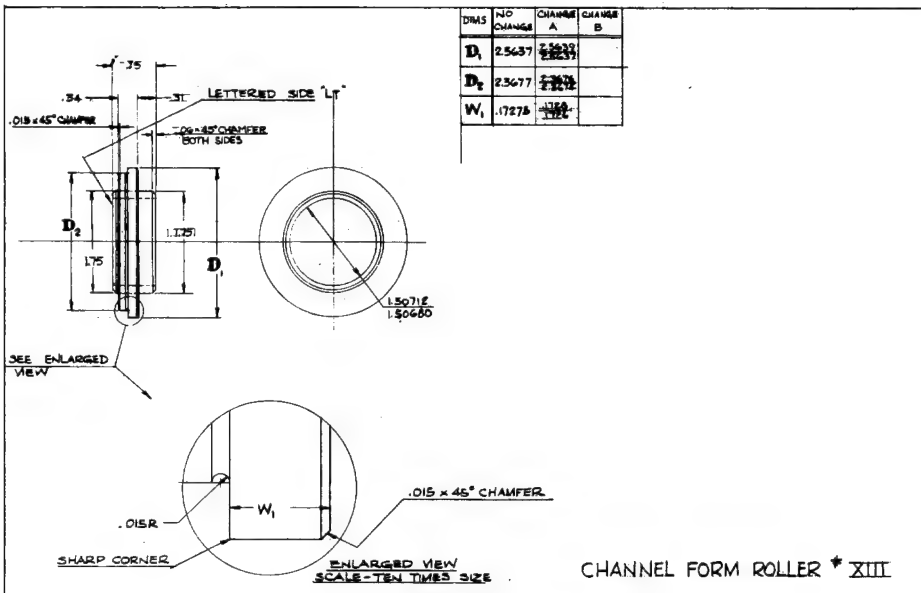
ALL ANGLES $\pm 2^\circ$ FINISH DIMS $\pm .010$ FINISH ALL OVER \checkmark

A SURFACES CONSTRUCTED
AROUND OR AT RIGHT ANGLES
TO A COMMON AXIS WHEN PART IS
MOUNTED ON SURFACE X MUST
BE WITHIN FULL INDICATOR
READING SPECIFIED

FOR SIDE ROLLER DETAILS
AND SECTION SHOWING ROLLERS
IN ROLLING POSITION SEE
LS 25754 SH 2

ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.	Z	DESCRIPTION	MAT'L	OTHER SPECS	FORG. CAST W.R.
	ADD.		REFERENCE	CANCEL					
PARTS LIST									
SCALE	1/1								
JOB NUMBER									
Curtiss-Wright Co.						I WIRE ROLLERS - FINISH		LS25754	
WRIGHT AERONAUTICAL CO.									
WOOD-RIDGE, NEW JERSEY, U.S.A.									

Figure 21



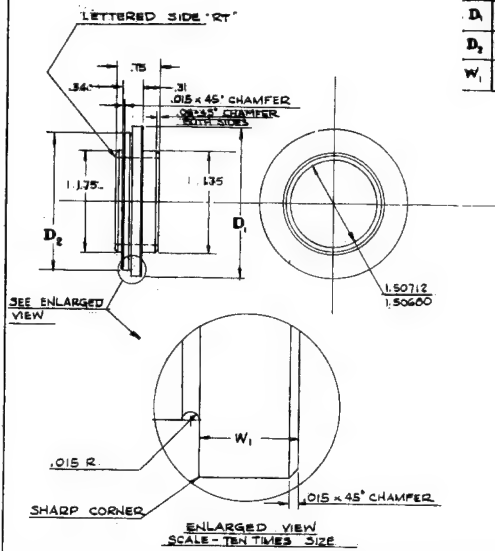
LETTER

LETTERED SIDE 'LT'

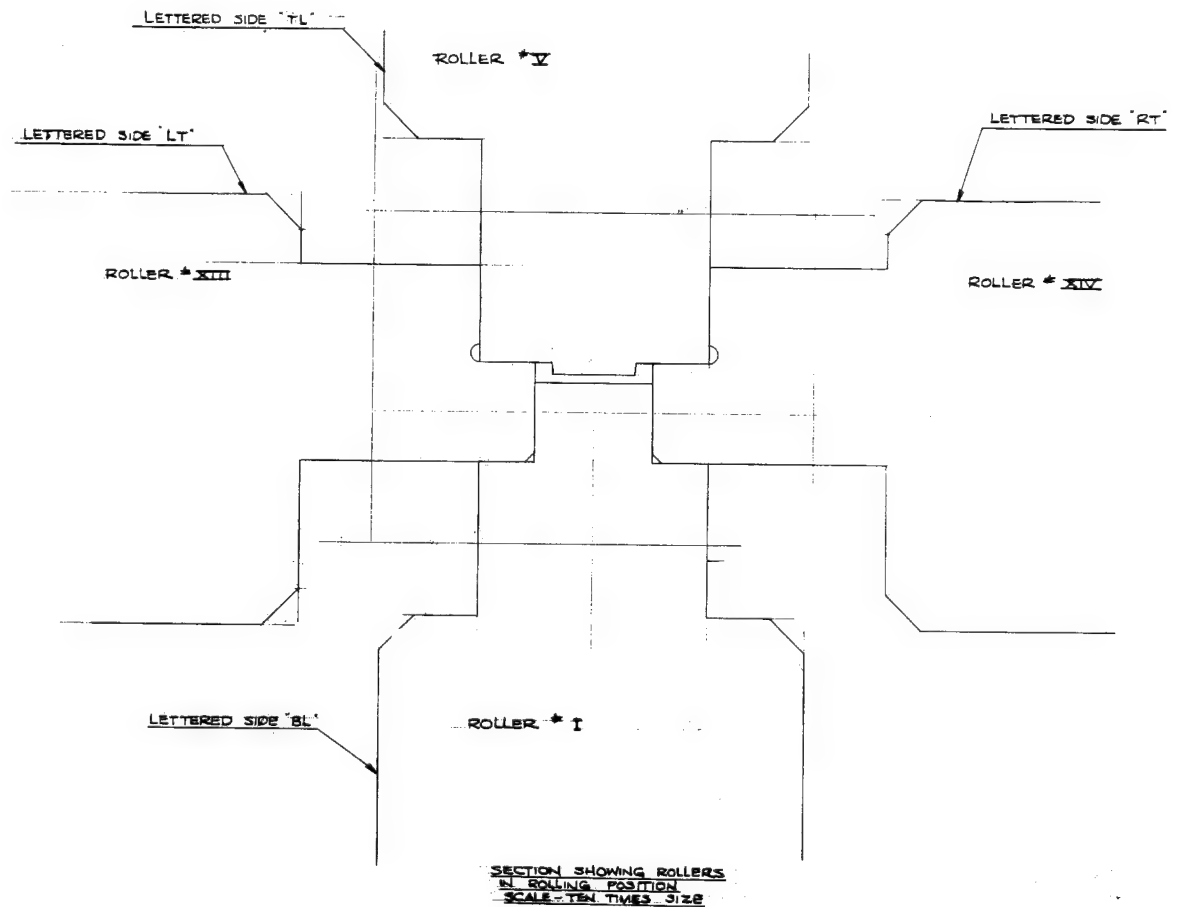
ROLLER *

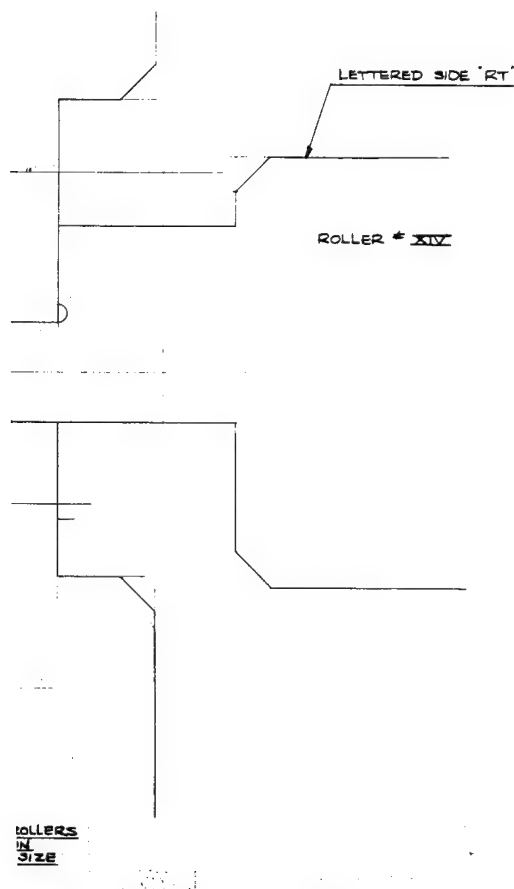
LETT

QMS	NO	CHANGE	CHANGE
	CHANGE	A	B
D ₁	2.5638	2.5633	
D ₂	2.3675	2.3670	
W ₁	.1787	.1782	



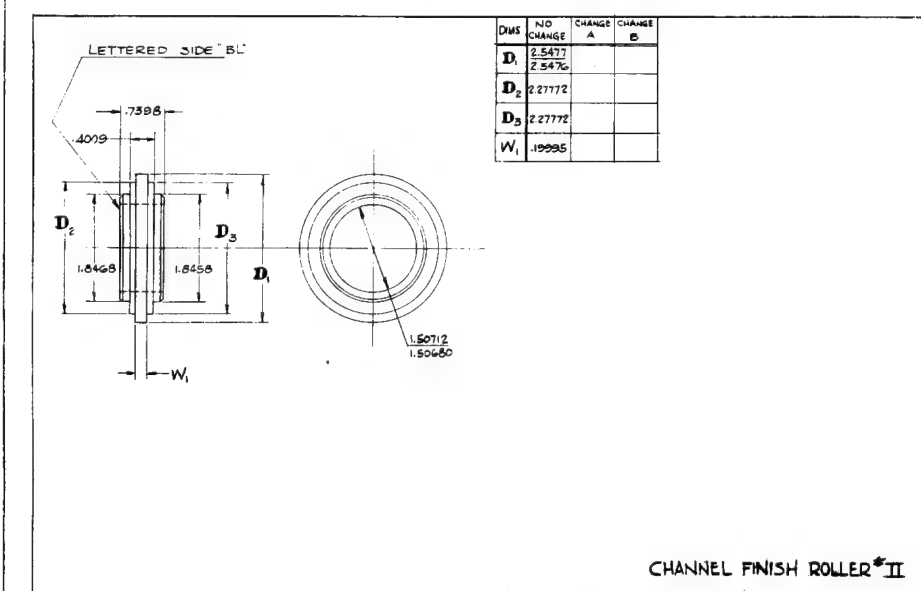
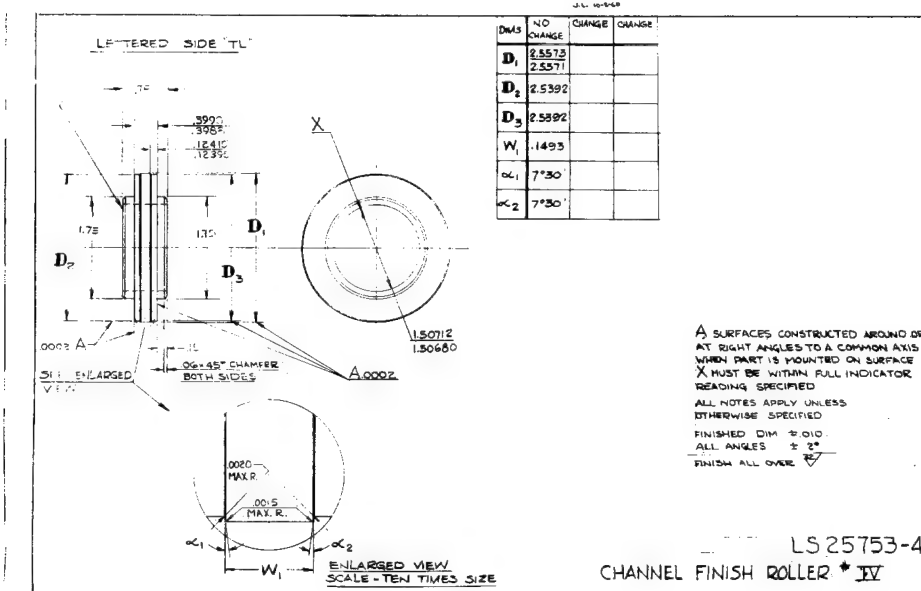
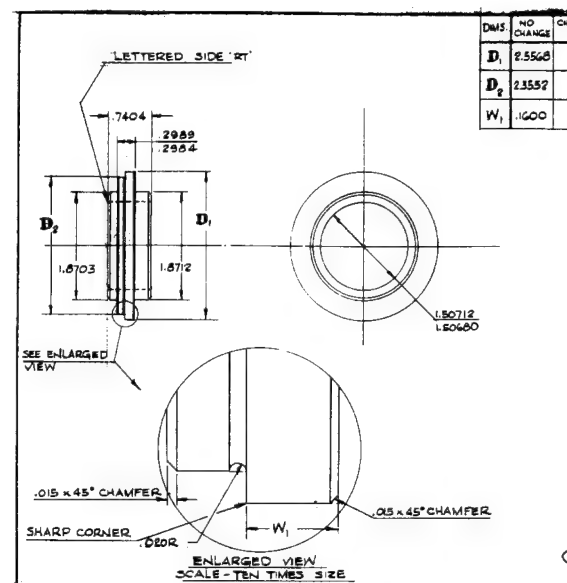
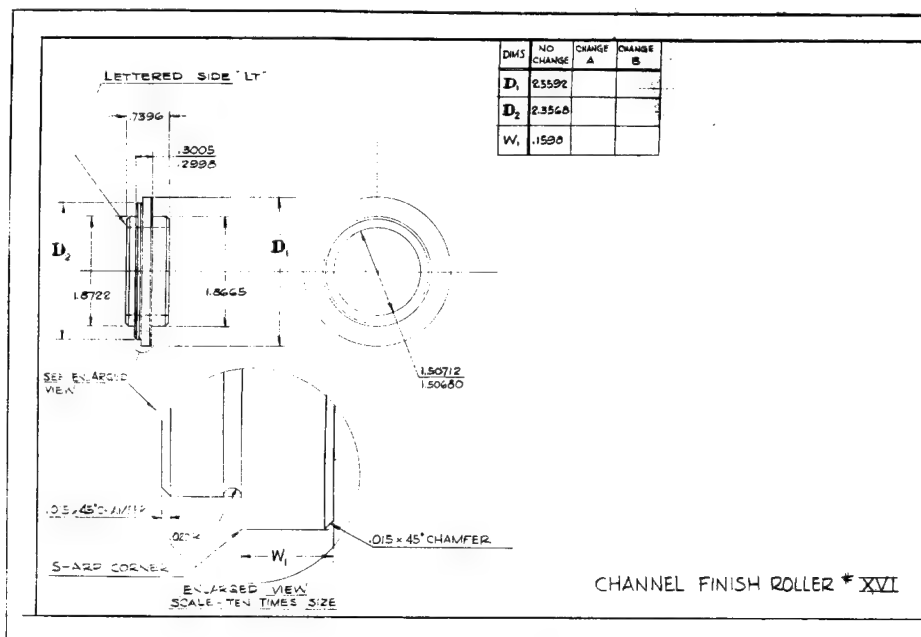
CHANNEL FORM ROLLER *XIV





LS 25753
SH. 1

CHANNEL WIRE ROLLERS FORM



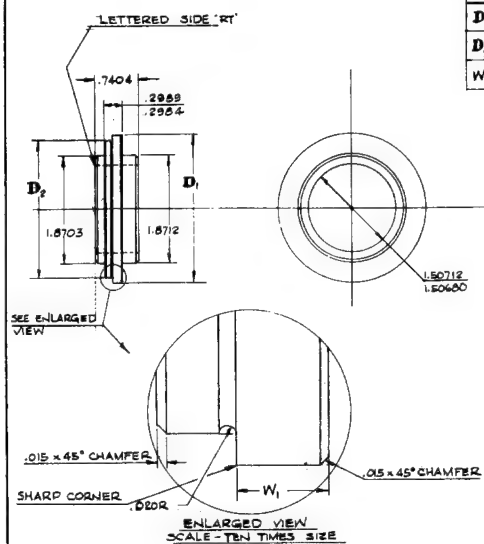
LETTERED SIDE

LETTERED SIDE "LT"

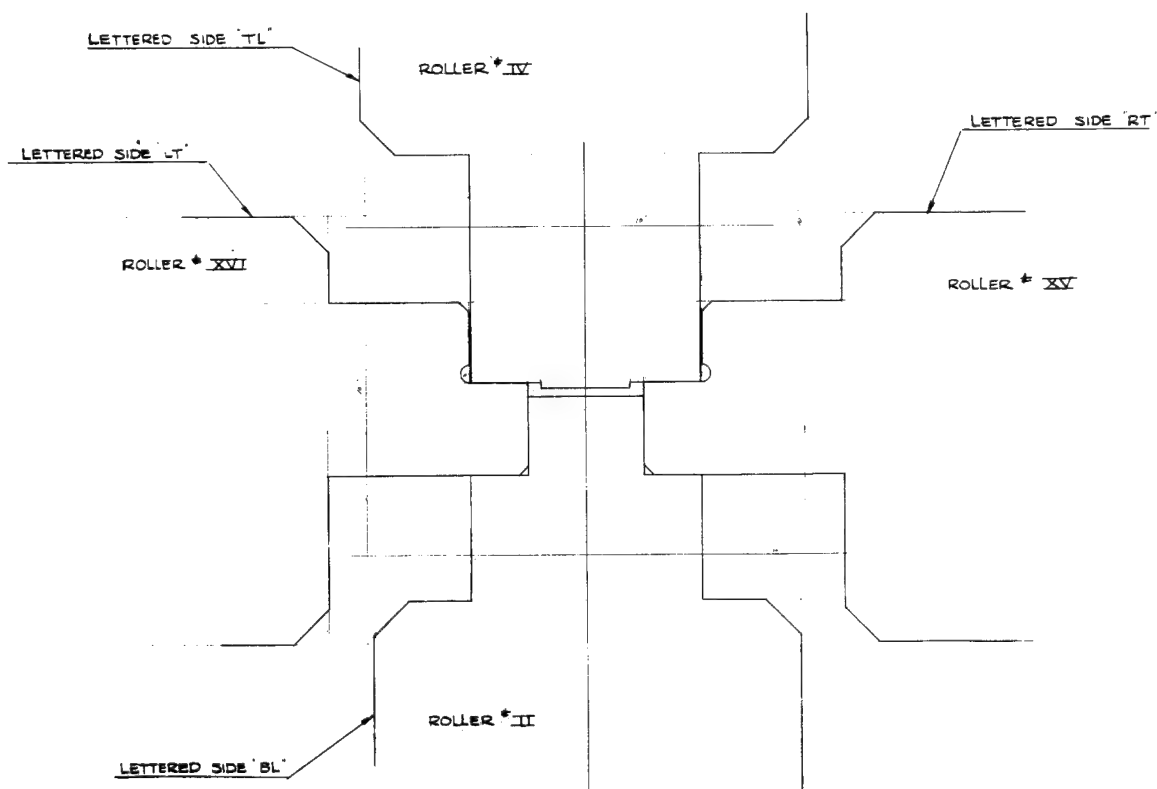
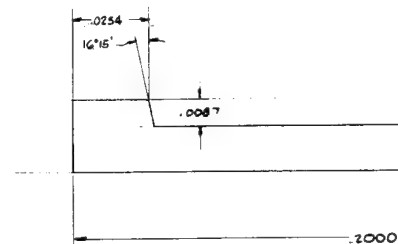
ROLLER #

LETTERED

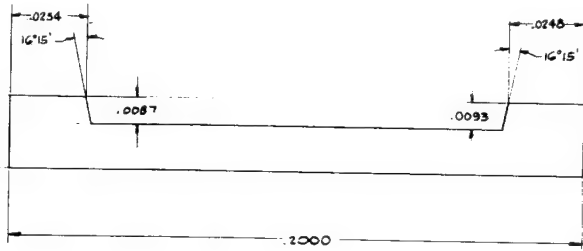
DIMS	NO CHANGE	CHAMFER A	CHAMFER B
D ₁	2.5565		
D ₂	2.3552		
W ₁	.500		



CHANNEL FINISH ROLLER # XV



SECTION SHOWING ROLLERS
IN ROLLING POSITION
SCALE - TEN TIMES SIZE



LETTERED S.D.E. RT.

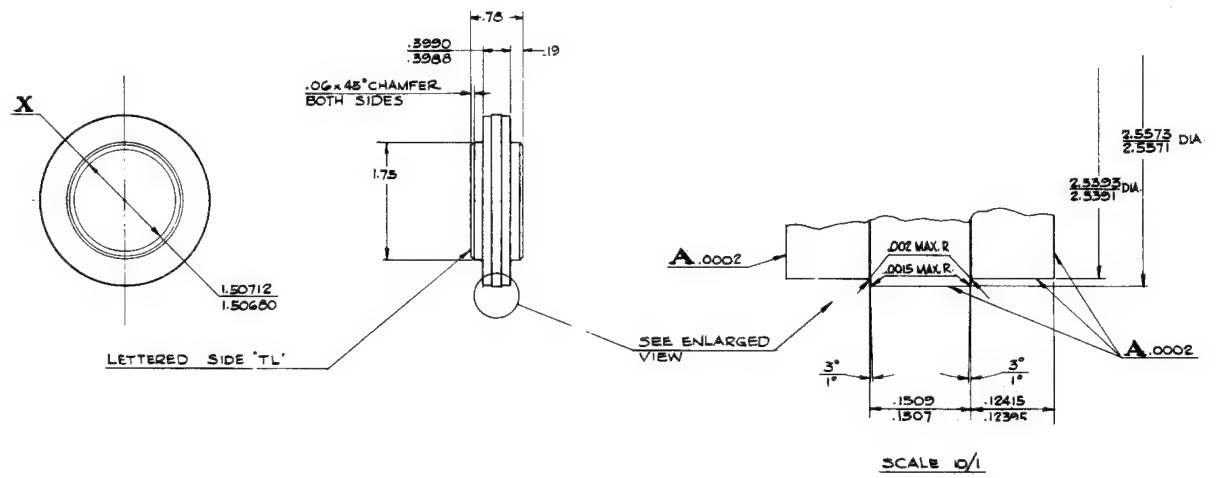
ROLLER # XV

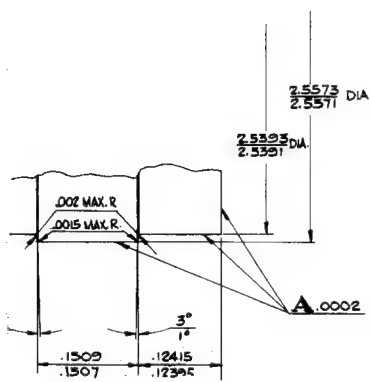
LS 25753
SH. 2

IONING ROLLERS
POSITION
TIMES SIZE

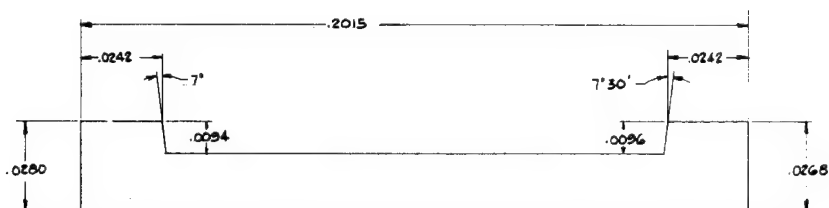
ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.	DESCRIPTION	MAT'L.	OTHER	FORG.
SCALE					PARTS LIST			
JOB NUMBER					EXCHANGING NO.			
CURTIS-WRIGHT CORP. WRIGHT AERONAUTICAL DIV. WRIGHT-PATTERSON, NEW JERSEY, U.S.A.					CHANNEL RIGID ROLLERS (FINISH)			
					LS 25753			

Figure 23



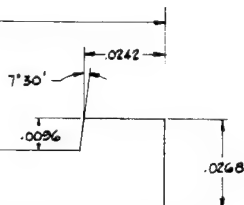


SCALE 10/1



UNLESS OTHERWISE SPECIFIED (ALL ANGLE
FINISH D
FINISH A
A SURFACE
AROUND C
TO A COM
MOUNTED
BE WITHIN
READING
FOR SIDE
DETAILS A
ROLLERS
SEE LS 2

MILITARY SPECIFICATIONS	
SPEC NUMBER	REVISIONS
CURTISS-WRIGHT CORP WRIGHT AERONAUTICAL DIV. WOOD-RIDGE, NEW JERSEY, U.S.A.	
CHANNEL W FINISH	



LS25753

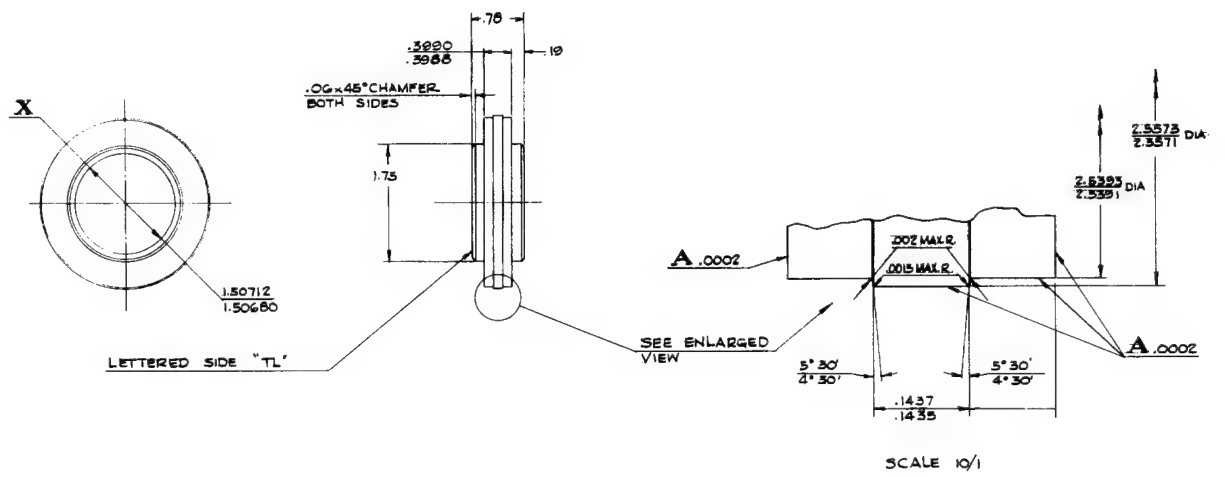
SH. 3

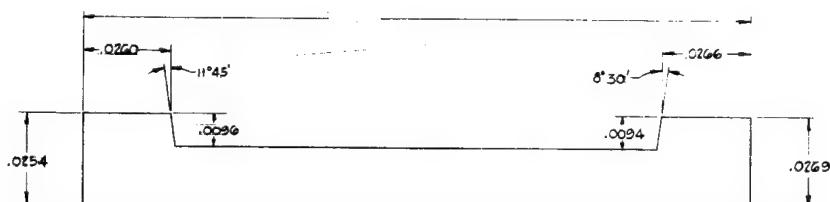
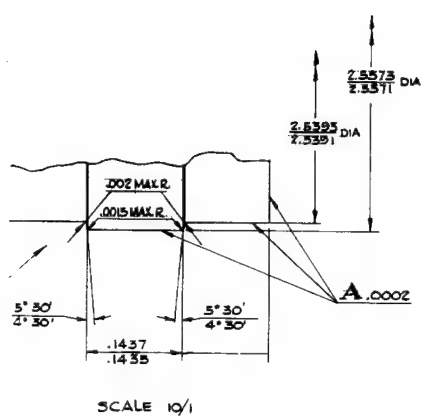
UNLESS OTHERWISE SPECIFIED { ALL ANGLES $\pm 2^\circ$
FINISH DIMS $\pm .010$
FINISH ALL OVER $\sqrt{\text{V}}$

A SURFACES CONSTRUCTED
AROUND OR AT RIGHT ANGLES
TO A COMMON AXIS WHEN PART IS
MOUNTED ON SURFACE X MUST
BE WITHIN FULL INDICATOR
READING SPECIFIED

FOR SIDE ROLLER & BOTTOM ROLLER
DETAILS AND SECTION SHOWING
ROLLERS IN ROLLING POSITION
SEE LS 25753 SH 2

MILITARY SPECIFICATIONS		APPROVED					
DATE	REVISION	BY	CHKD	DESIGN	TEST	PROD	REMARKS
		11/14/61	CRICKER	STP-2	100	DEVELOPT	
		4/17/66					
CURTIS-WRIGHT CORP. WRIGHT AERONAUTICAL DIV. WOOD-RIDGE, NEW JERSEY, U. S. A.		CHANNEL WIRE ROLLERS- FINISH		LS25753			
				SH. 3 OF 4 SHEETS			

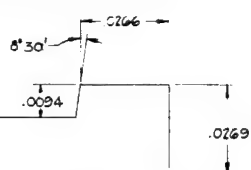




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MILITARY SPECIFICATIONS	
TYPE	DEVIATIONS
CURTISS-WRIGHT CORP WRIGHT AERONAUTICAL DIV. WOOD-RIDGE, NEW JERSEY, U. S. A.	



LS 25753

SH 4

UNLESS OTHERWISE SPECIFIED (ALL ANGLES $\pm 2^\circ$)
 FINISH DIMS $\pm .010$
 FINISH ALL OVER \sqrt{V}
 A SURFACES CONSTRUCTED
 AROUND OR AT RIGHT ANGLES
 TO A COMMON AXIS WHEN PART IS
 MOUNTED ON SURFACE X MUST
 BE WITHIN FULL INDICATOR
 READING SPECIFIED

FOR SIDE ROLLER & BOTTOM ROLLER
 DETAILS AND SECTION SHOWING
 ROLLERS IN ROLLING POSITION
 SEE LS 25753 SH. 2

MILITARY SPECIFICATIONS		APPROVAL					
SPEC. NUMBER	REVISION	BY	DESIGNED	DESIGN SUPER	PROT. ENG. DESIGN	PROT. ENG. DEVELOP.	PROT. ENG. PERMANENT
		1/17/60					
		1/17/60					
		1/17/60					
CURTISS-WRIGHT CORP WRIGHT AERONAUTICAL DIV. WOOD-RIDGE, NEW JERSEY, U. S. A.		CHANNEL WIRE ROLLERS- FINISH		LS25753			
				SH 4 OF 4 SHEETS			

Figure 25

"I" BEAM ROLLER ANGLE VS. TAPE ANGLE

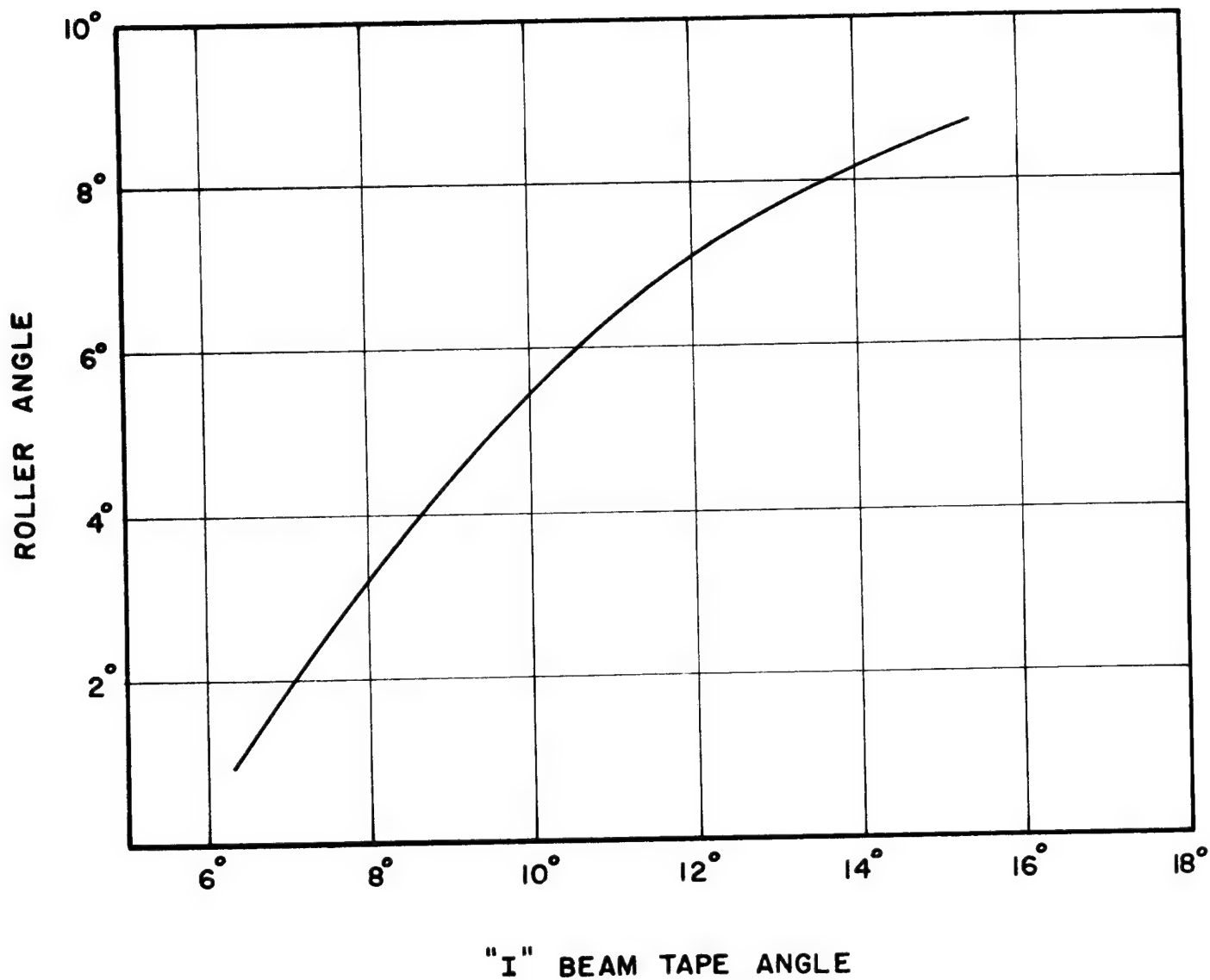
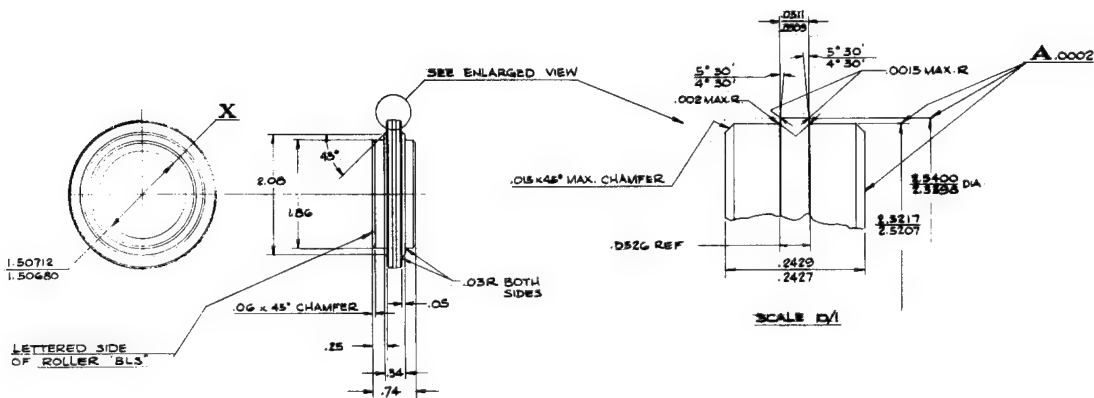
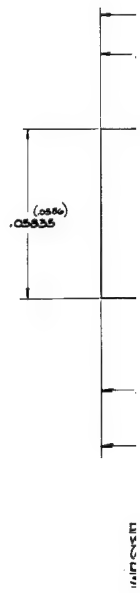
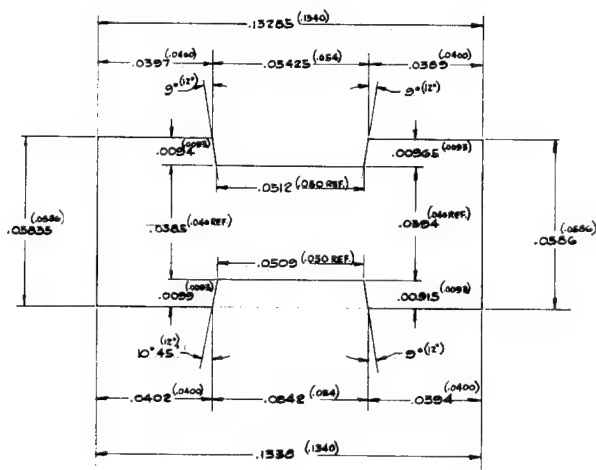


Figure 20
30





DIMENSIONS OF WIRE SAMPLE MADE
WITH ROLLERS SHOWN AT LEFT
(AVERAGE OF 2 SAMPLES)
DESIRED DIMENSIONS GIVEN IN PARENTHESES
SCALE 50/1

UNLESS OTHERWISE SPECIFIED

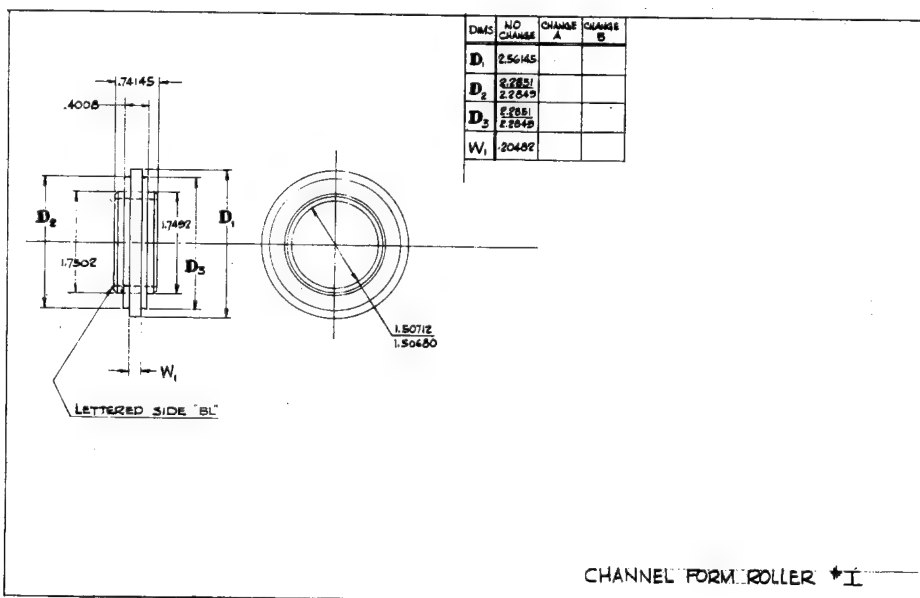
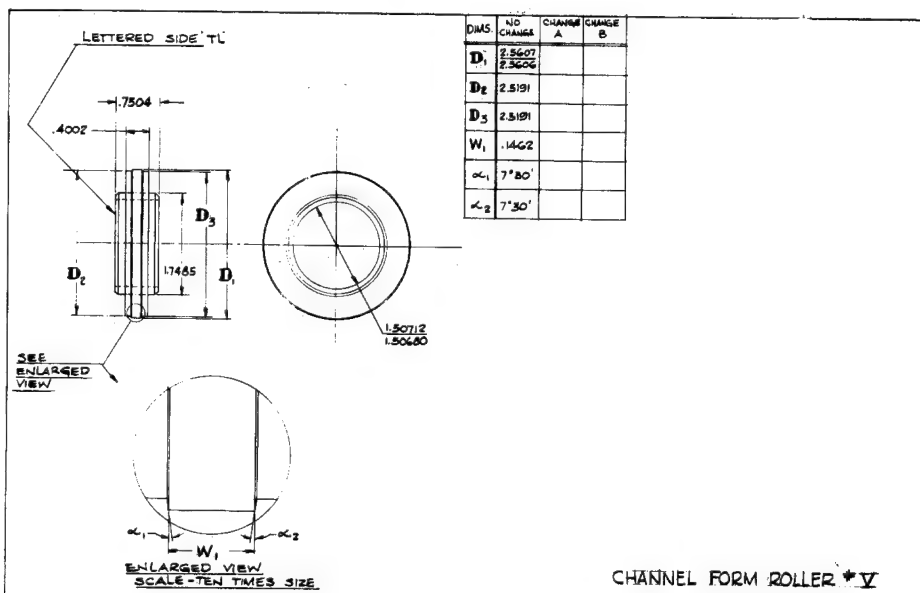
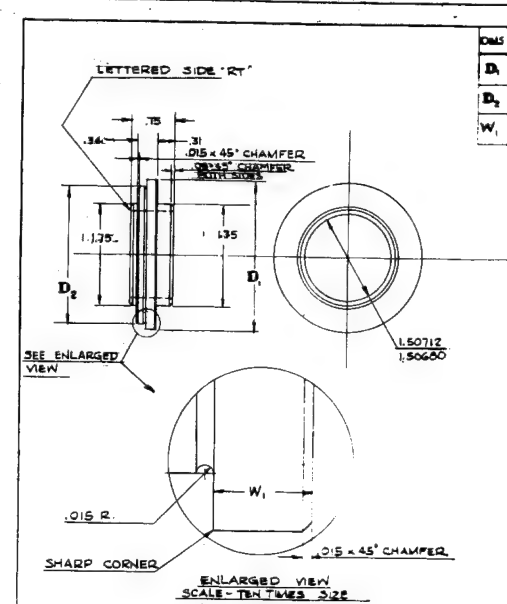
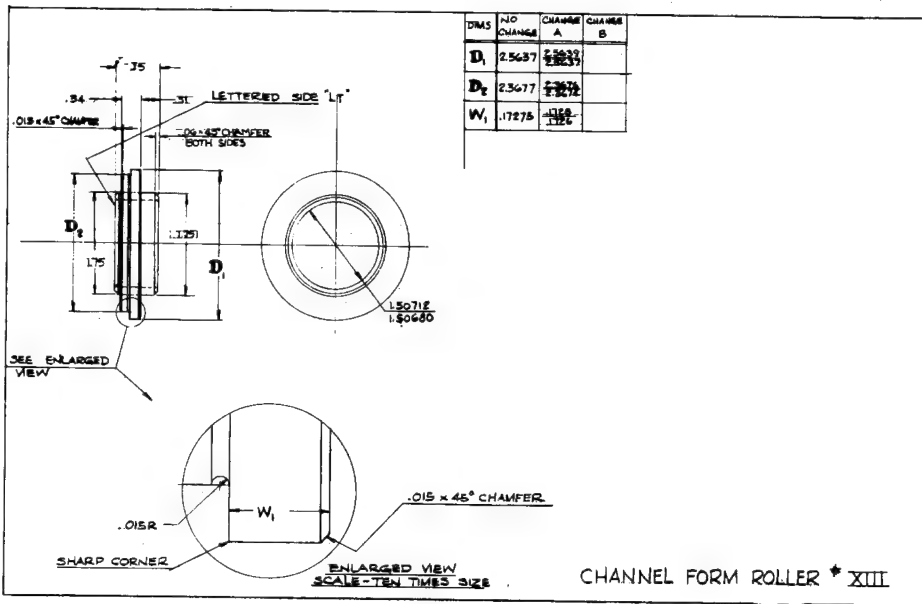
ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.
ADD		REFERENCE CANCEL		
SCALE 1/1		DATE 1/1/54		
JOB NUMBER		DRAWN BY 1/1/54		
		CHECKED BY 1/1/54		
CURTISS-WRIGHT CO.				
WRIGHT AERONAUTICAL DIV.				
WOODBRIDGE, NEW JERSEY, U.S.A.				



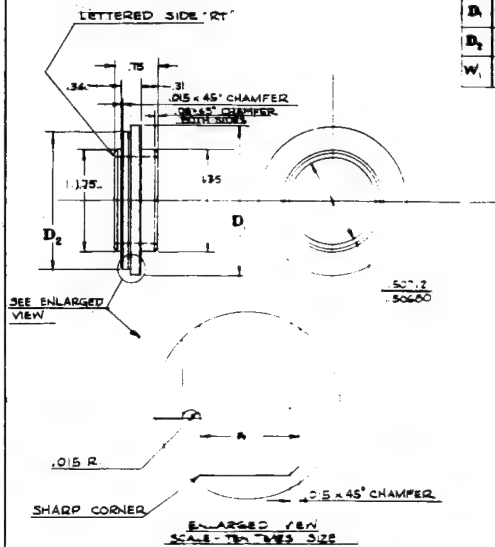
SH. 4

A SURFACES CONSTRUCTED
AROUND OR AT RIGHT ANGLES
TO A COMMON AXIS WHEN PART IS
MOUNTED ON SURFACE X MUST
BE WITHIN FULL INDICATOR
READING SPECIFIED
FOR SIDE ROLLER DETAILS
AND SECTION SHOWING ROLLERS
IN ROLLING POSITION SEE
LS 23754 SH 2

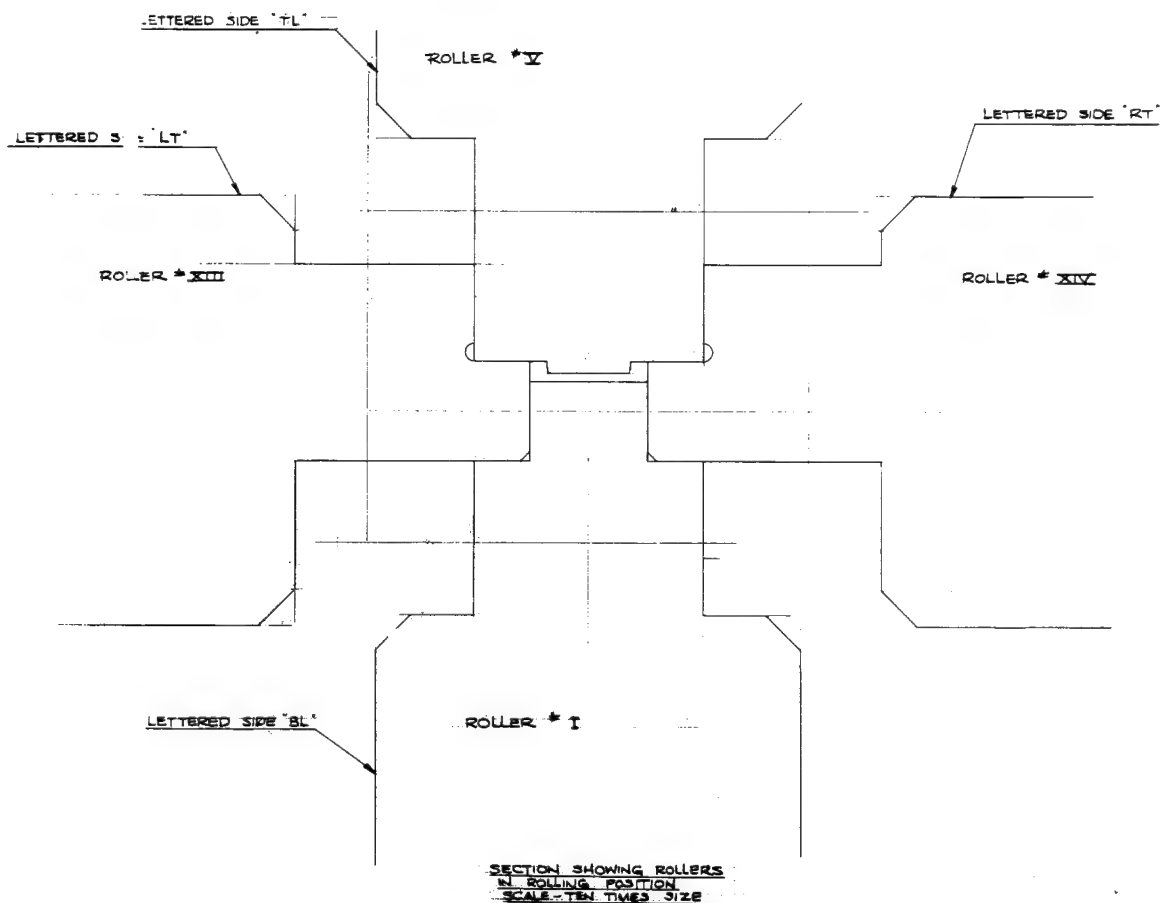
Figure 21



QMS	NO	CHG	CHG
	CHG	A	B
DA	2.5648	2.5648	2.5648
DB	2.5675	2.5675	2.5675
W	.7787	.7787	.7787



CHANNEL FORM ROLLER *XIV



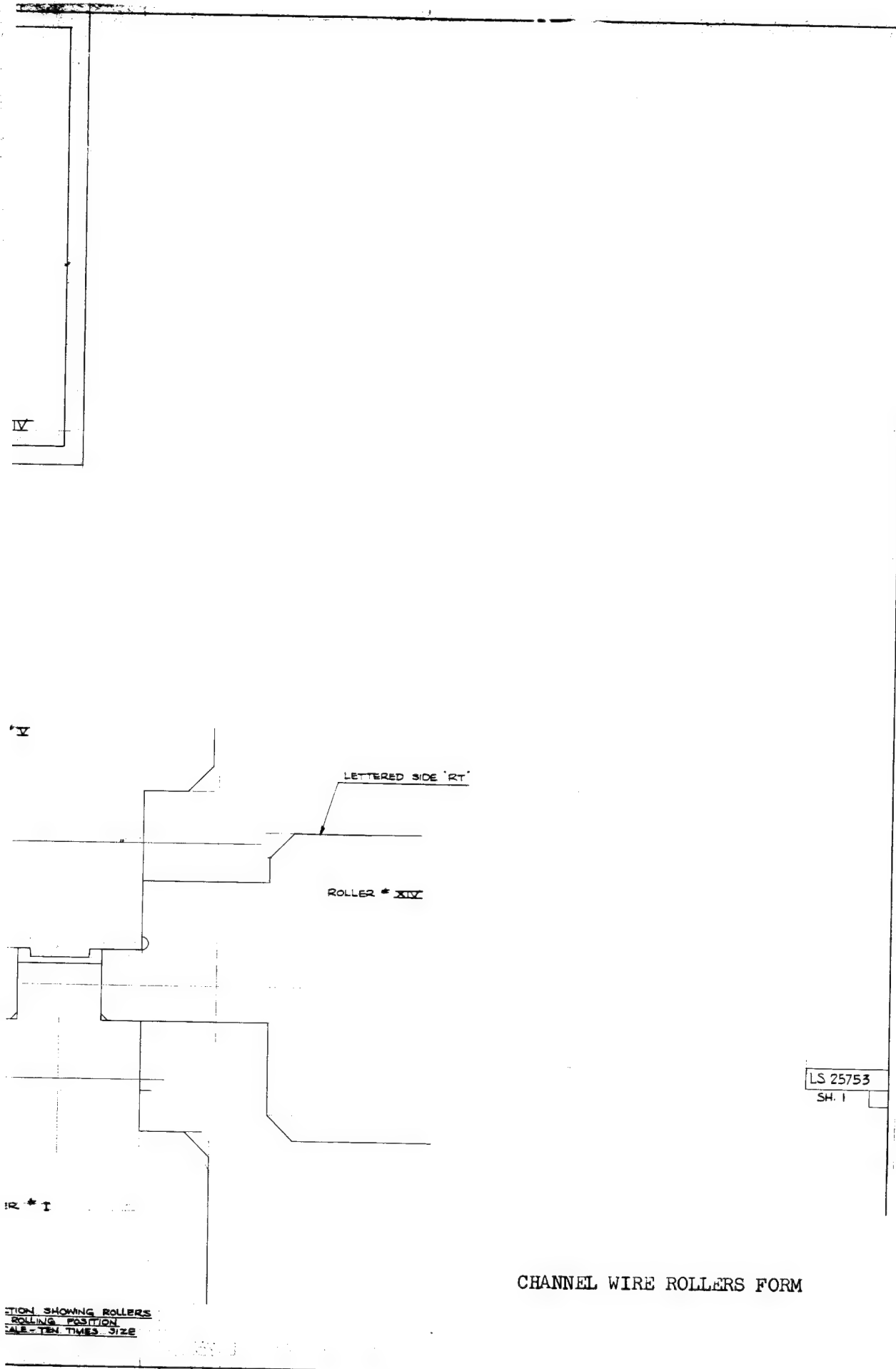
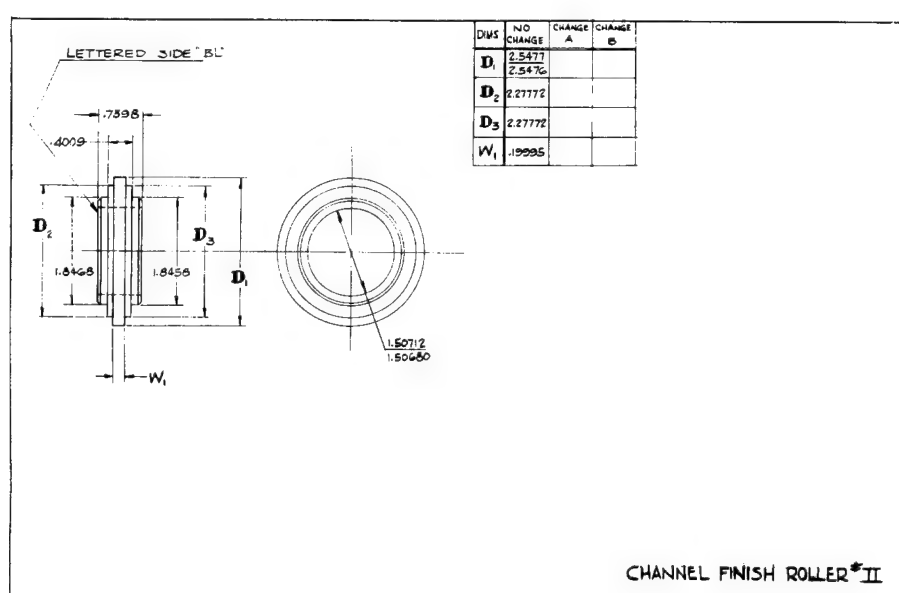
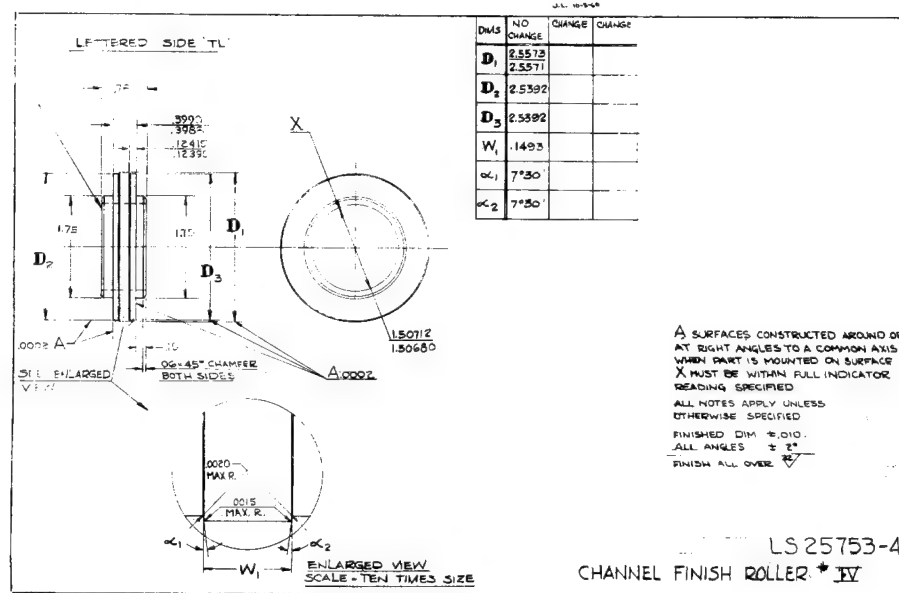
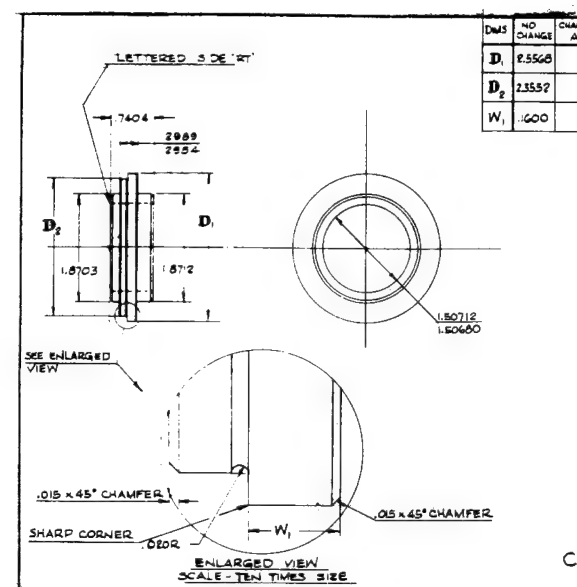
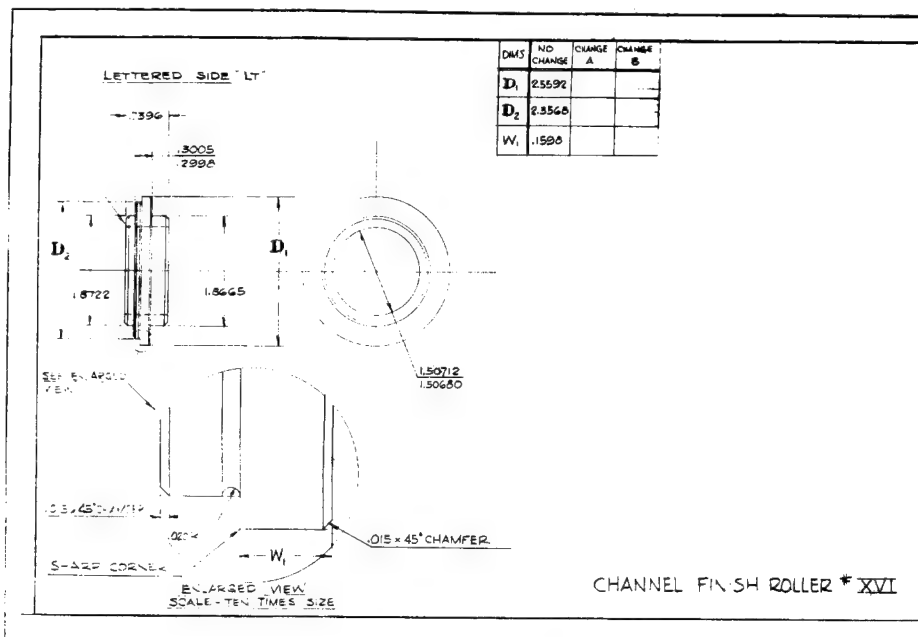


Figure 22
32

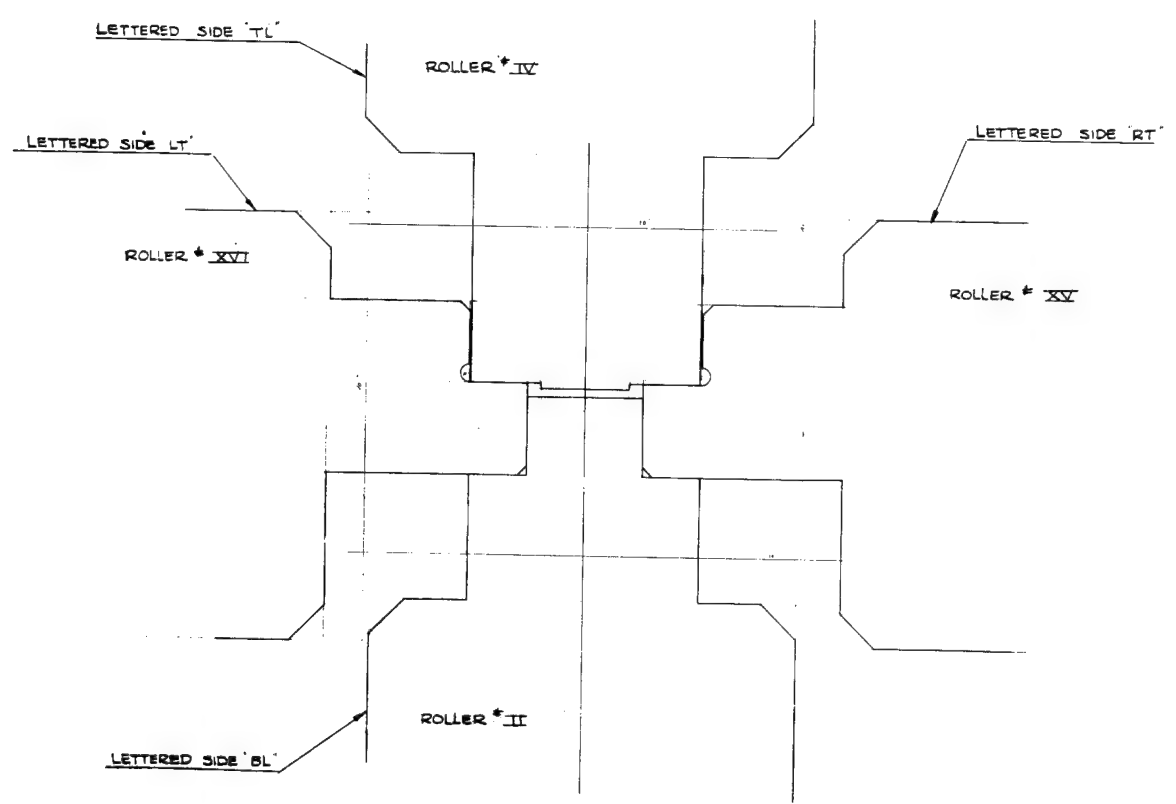
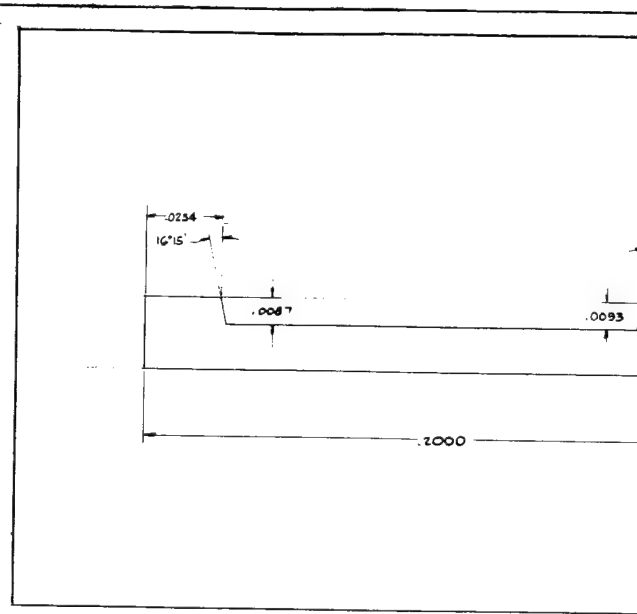
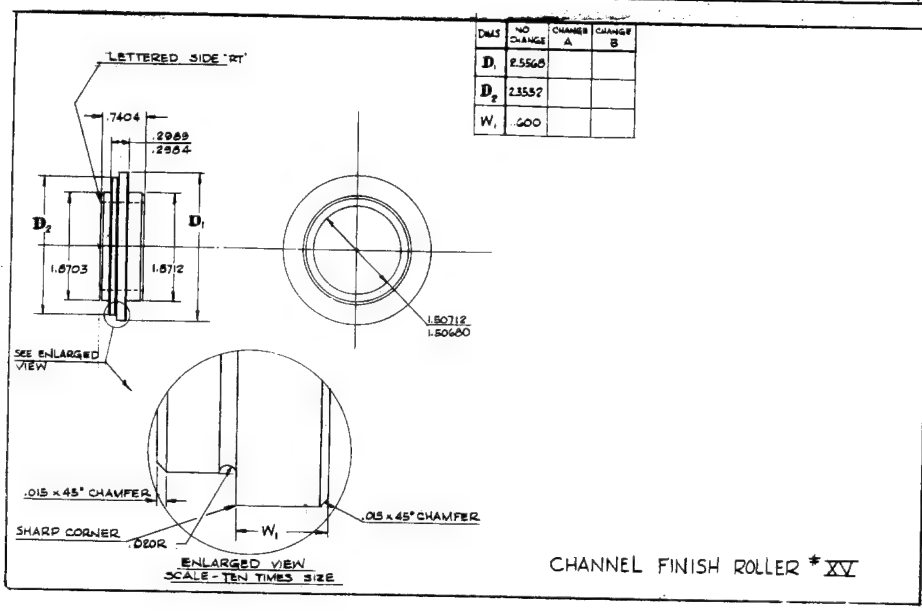


LETTERED SIDE

LETTERED SIDE "LT"

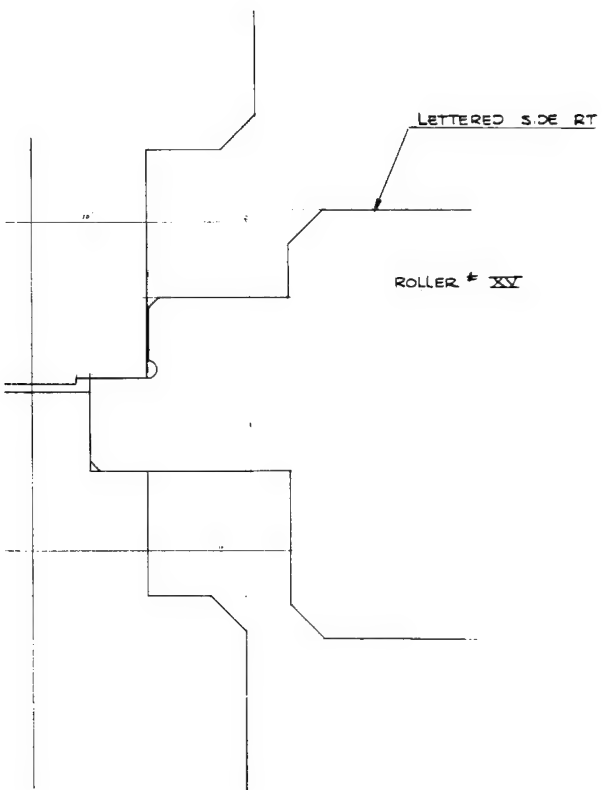
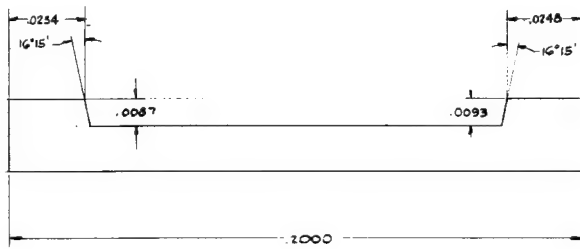
ROLLER * X

LETTERED SIDE



SECTION SHOWING ROLLERS
IN ROLLING POSITION
SCALE - TEN TIMES SIZE

ITEM NO.	PART NO.
ADD.	
SCALE	
JOB NUMBER	
CURT	
WEEK	
YEAR	

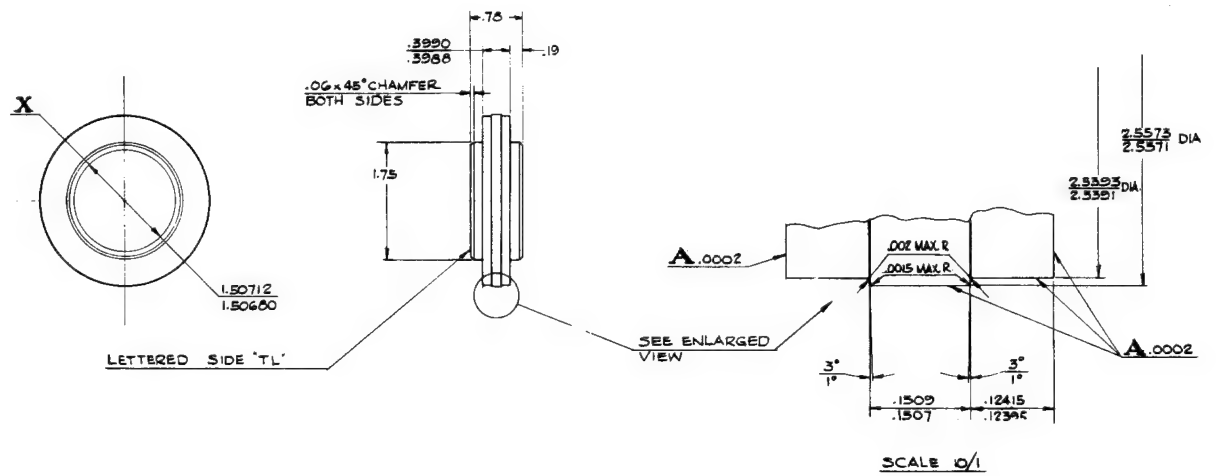


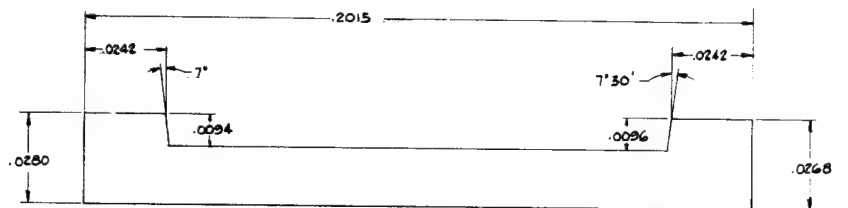
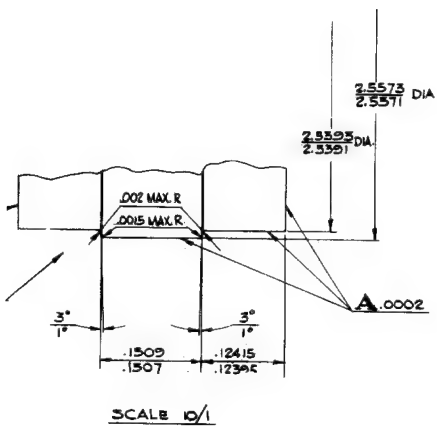
LS 25753
SH. 2

SHOWING ROLLERS
POSITION
N TIMES SIZE

ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.	2	DISTRIBUTION	MAT'L	OTHER SPECS	FORD CAST W.R.
ADD		REFERENCE		CANCEL		PARTS LIST			
SCALE		DATE		BY		S. L.		W. S. G.	
JOB NUMBER		PART NO.		P. NO.		P. NO.		P. NO.	
CURTIS-WRIGHT CORP.		WRIGHT AERONAUTICAL DIV.		WRIGHT AERONAUTICAL DIV.		WRIGHT AERONAUTICAL DIV.		WRIGHT AERONAUTICAL DIV.	
CHAMBERLAIN ROLLERS		(FINISH)		LS 25753		SH. 2		SH. 2	

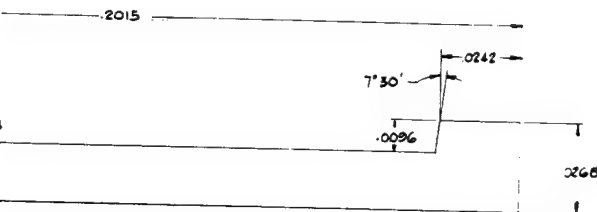
Figure 23





UNLESS OTHERWISE SPECIFIED

MILITARY SPECIFICATION	
QFC	DI
CURTISS-WRIGHT CORP.	
WRIGHT AERONAUTICAL DIV.	
WOOD-RIDGE, NEW JERSEY, U. S. A.	



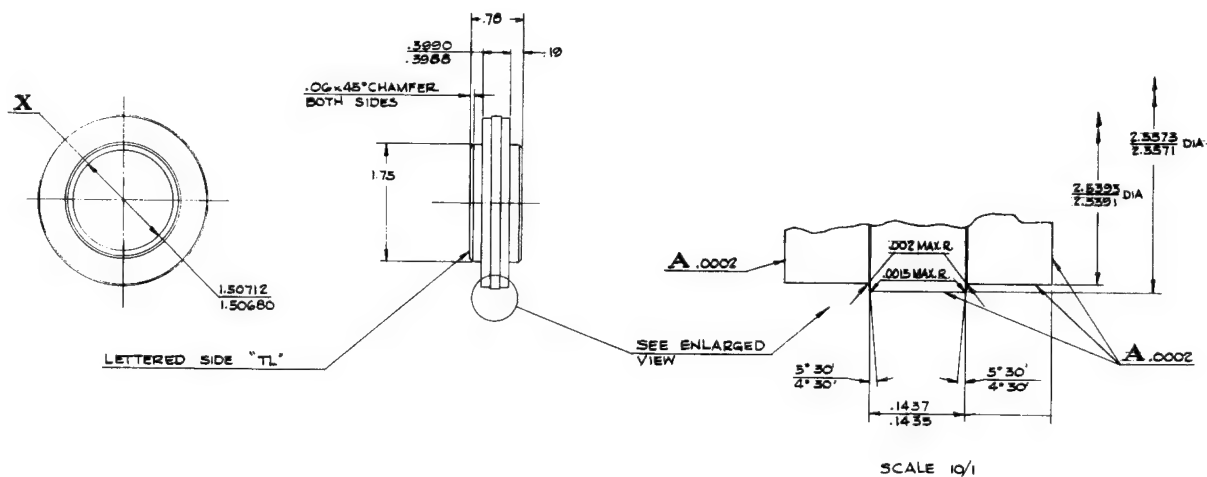
LS 25753
SH. 3

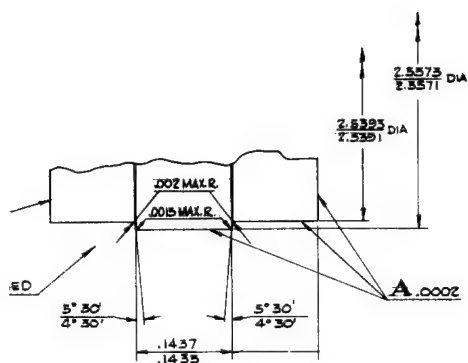
UNLESS OTHERWISE SPECIFIED (ALL ANGLES $\pm 2^\circ$)
 FINISH DIMS $\pm .010$
 FINISH ALL OVER $\sqrt{\text{V}}$
A SURFACES CONSTRUCTED
AROUND OR AT RIGHT ANGLES
TO A COMMON AXIS WHEN PART
MOUNTED ON SURFACE X MUST
BE WITHIN FULL INDICATOR
READING SPECIFIED
FOR SIDE ROLLER & BOTTOM ROLLER
DETAILS AND SECTION SHOWING
ROLLERS IN ROLLING POSITION
SEE LS 25753 SH 2

MILITARY SPECIFICATIONS		APPROVAL		REVISIONS			
DATE	DESCRIPTION	BY	CHKD	REVISION	DATE	BY	CHKD
11/14/60		STARTING					
11/17/60		COMPLETED					

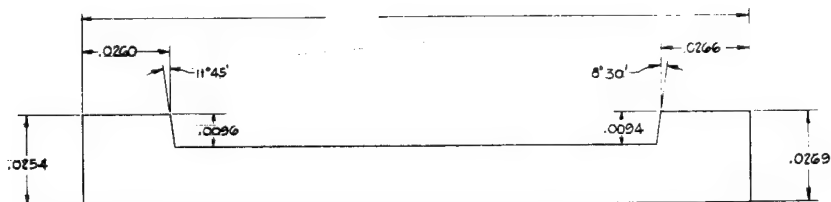
CURTIS-WRIGHT CORP. WRIGHT AERONAUTICAL DIV. WOOD-RIDGE, NEW JERSEY, U. S. A.	CHANNEL WIRE ROLLERS- FINISH	LS25753 SH. 3 OF 4 SHEETS
---	---------------------------------	------------------------------

Figure 24





SCALE 10/1



UNLESS OTHERWISE SP



FINISH ALL OVER $\sqrt{32}$

FOR SIDE ROLLER & BOTTOM ROLLER
DETAILS AND SECTION SHOWING
ROLLERS IN ROLLING POSITION
SEE LS 25753 34.2

34 OF 4 SHEETS

35

CHANNEL ROLLER ANGLE VS TAPE ANGLE

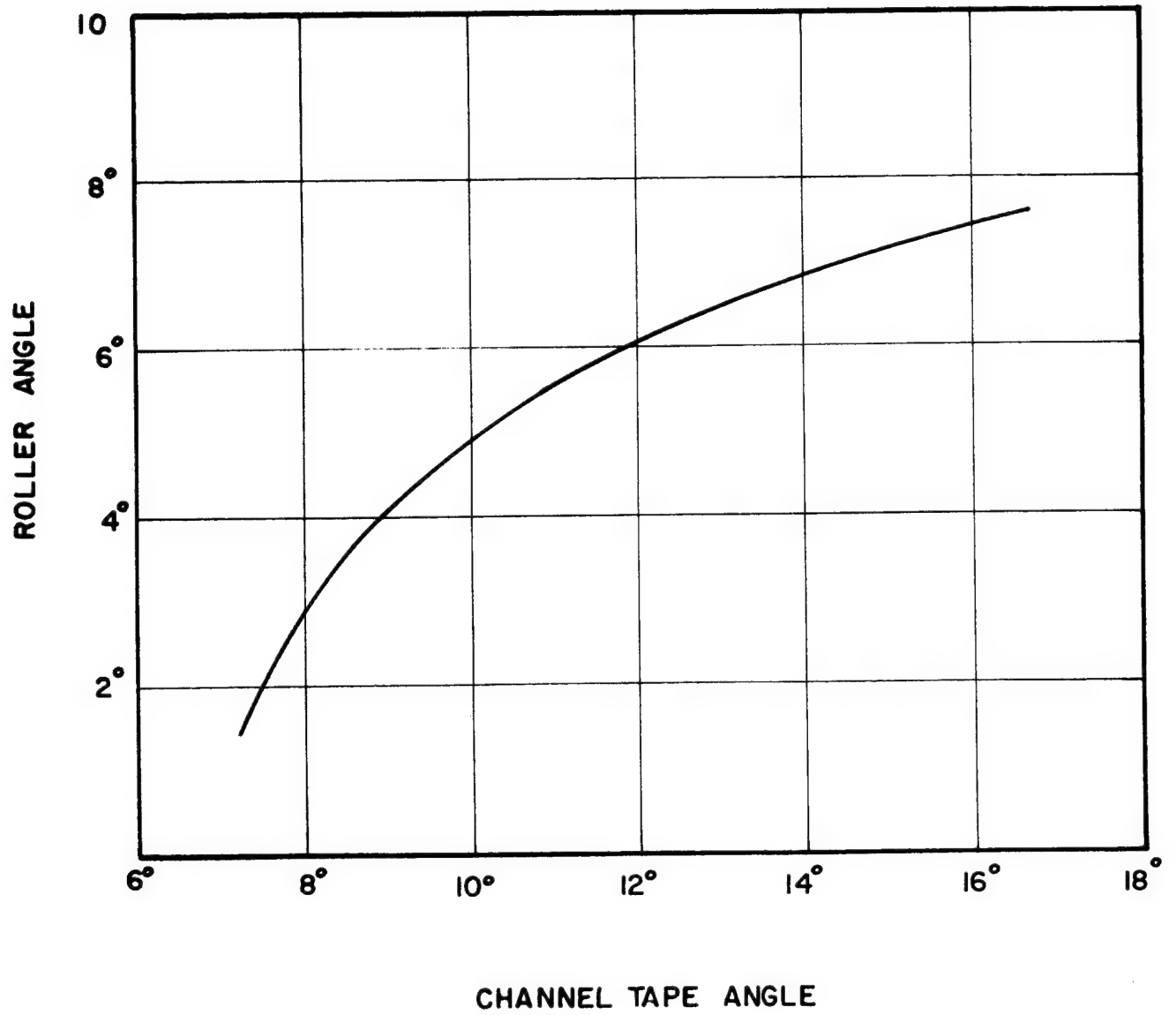


Figure 26
36

5.0 METALLURGY

5.0 METALLURGY

5.1 Work Statement

Metallurgical work carried out under the present contract includes tape manufacture, development of measuring techniques, measurement of interference fit, development of heat treatment, determination of frictional coefficients, evaluation of liner and bonding methods and a limited number of low temperature tensile tests.

5.2 Starting Material

Commercial Bl20VCA titanium alloy weld wire produced by centerless grinding and drawing was procured in the mill annealed condition. Two sizes, .154" and .123" were evaluated resulting in the final selection of .123" nominal gage for both shapes. The fabrication of lengths in excess of 100 ft., though successful in some heats, resulted in cracking and rupture in the case of the most recently purchased material. Poor wire surface in "as received" material was observed to contribute to this problem. Superficial pickling, either acid or basic, found effective in improving surface condition was not always found to alleviate the problem. Other possible causes include hydrogen embrittlement, surface contamination, and variances in chemical composition. In order to insure quality and uniformity in future purchases a specification for Bl20VCA material in the form of coils of wire was prepared. This specification is reproduced in detail in Appendix III.

5.3 Rolling Techniques

5.3.1 Round Wire Breakdown

5.3.1.1 "I" Beam

The round wire discussed in Section 5.2 is cold reduced to a rectangular shape prior to further reduction in the Turks head mill. Originally, a Universal Turks head was used to produce all rectangular shapes. This procedure was abandoned in favor of a more rapid procedure which utilizes power driven rolls. The current breakdown is carried out in a groove mill and a flat mill, and is as follows:

5.3.1.1 "I" Beam (Continued)

<u>Pass No.</u>	<u>Mill</u>	<u>Thickness of Rectangle</u>	<u>Width of Rectangle</u>
1	Groove	.118	.118
2	Groove	.108	.108
3	Groove	.100	.100
4	Flat	.092	.108
5	Flat	.084	.116
6	Flat	.076	.124
7	Flat	.068	.132
8	Flat	.062	.140

5.3.1.2 Channel

The breakdown of round wire into rectangular cross-sections for the channel tape is more complicated since the amount of spread (.121" Dia. to .2165") is much greater. This procedure also requires the use of a groove mill and a flat mill, and is as follows:

<u>Pass No.</u>	<u>Mill</u>	<u>Thickness Rectangle</u>	<u>Width of Rectangle</u>
1	Groove	0.1050	0.1320
2	Groove	0.0990	0.1352
3	Groove	0.0950	0.1395
4	Groove	0.0900	0.1425
5	Groove	0.0855	0.1466
6	Flat	0.0810	0.1510
7	Flat	0.0760	0.1570

5.3.1.2 Channel (Continued)

<u>Pass No.</u>	<u>Mill</u>	<u>Thickness of Rectangle</u>	<u>Width of Rectangle</u>
8	Flat	0.0720	0.1615
9	Flat	0.0590	0.1760
10	Flat	0.0540	0.1816
11	Flat	0.0494	0.1887
12	Flat	0.0443	0.1950
13	Flat	0.0396	0.2030
14	Flat	0.0350	0.2100
15	Flat	0.0310	0.2165

The problem of reducing round wire to the rectangular starting shapes necessary for Turks heading was further complicated by the necessity of avoiding the use of oxide coatings which normally serve as lubricants. Oxide coatings were found to result in embrittlement in the subsequent Turks heading operation.

5.3.2 Turks Heading of Rectangular Wire

Initially, two procedures of cold reducing rectangular B120VCA titanium wire were considered. Use of power driven rolls in a "shell mill" was believed to offer the advantages of spreading rather than elongating the material and allowing heavier reductions per pass because no extremely heavy pull was needed. It was, however, found that the accuracy of the shell mill was not sufficient to maintain the critical internal shapes, particularly the angles. Heavy passes resulted in cracking of the wire. Intermediate annealing was discarded since it lowered the attainable strength of the final product. Emphasis was, therefore, placed on the Turks heading method.

5.3.2 Turks Heading of Rectangular Wire (Continued)

This method, utilizing idling rolls through which wire is drawn, was believed to offer greater flexibility and sensitivity of adjustment, hence, better accuracy. The Turks head mill is an apparatus comprising four rolls which are housed at a 90° angle to one another. Depending on the model, the rolls may be adjusted independently or in pairs. The rolls can move in one direction only, i.e., up or down. A third available model, the "combination" Turks head incorporates the above and in addition, provides means for lateral adjustment.

It was initially thought that by limiting reductions in each pass to a small percentage, large total reductions in area could be obtained. In addition, it appeared advisable to employ one or more intermediate anneals.

Numerous samples were produced by thus "babying" the material, but with varying degrees of success. Intermediate anneals were found to reduce the final attainable strength. It was found that optimum aging response was obtained when the cold worked material after the final pass exhibited a tensile yield strength of 210,000 psi.

Patterning the shaping steps for either the "I" beam or channel shapes after steel mill practice proved unrewarding since the flow characteristics of titanium are totally different. The forming rolls, each taking relatively heavy reductions, were arrived at by trial and error. An extremely heavy finishing pass was necessary in order to avoid steps in the internal walls.

Though the finished dimensions obtained by the heavy reduction method proved superior to those produced by the previously used light reduction method, a number of new problems were introduced. These problems included cracking of the rolls as well as excessive wear of the roll arbors. Changes in the roll materials, heat treatment and chrome plating of arbors, though successful to a limited extent, were not considered satisfactory for rolling long lengths. Consequently, a larger Turks head mill (No. 3TH) was purchased. This resulted in lower Hertz stresses in the rolls and lower bearing stresses in the arbors. A Kerosene-water mixture was used as a lubricant.

5.3.2 Turks Heading of Rectangular Wire (Continued)

The techniques developed for the processing of tape in the small mill were found applicable in the larger mill, resulting in the successful production of the desired shape (Figure 3). Roll design, spring back calculations and modifications of rolls are reported in another portion of the present report (Section 4).

5.3.2.1 "I" Beam

Using the procedure outlined in the above section, the best "I" beam shape was produced in two (2) heavy passes. The first pass reduced the webb to 0.0416 and the overall length to .1370. The final pass reduced the webb to .0395 and the length to 0.134.

5.3.2.2 Channel

The final channel cross-section being smaller, but wider, than the "I" beam required somewhat smaller reductions. The following is the procedure employed for the manufacture of the channel type.

<u>Pass No.</u>	<u>Channel Webb Thickness</u>	<u>Channel Width</u>
1	.029	.2045
2	.027	.2043
3	.025	.2042
4	.023	.2041
5	.021	.2041
6	.0195	.2040
7	.0185	.2035
8	.0175	.2030
9	.0165	.2000
10	.0155	.2000

Figure 27 illustrates the major steps in the fabrication of the channel shape. As illustrated, shapes K through O contain ridges at the base of the channel which are used to force material to flow upward.

Figures 28 and 29 illustrate both cross sections in the etched and unetched condition. As may be observed from Figure 29, flow lines follow the internal corners indicating favorable flow with respect to the interference fit and final pressure vessel requirements.

5.4 Evaluation of Measuring Techniques

The measurement of both shapes has presented a serious problem due to the close tolerance requirement imposed. An investigation of several measuring methods was carried out. These include measurement by means of a comparator, projection by means of a metallograph, micrometer measurement of external dimensions, measurement of a calcium sulfate mold and use of toolmakers' microscopes and air gages.

The projection of both shapes by means of a comparator resulted in readings differing by as much as .0025 from outside dimensions as measured by a micrometer. This was primarily due to distortion in the tape produced by cutting. Glancing of the comparator beam from a flexed portion of the tape also proved inaccurate because of distortion.

The above attempt also showed that any twist or bend could produce erroneous results. This imposed the requirement that measurement must be made in a perpendicular plane. This was accomplished by copper plating (non-adhering) the tape to a thickness of approximately 0.005 inch. The tape was then placed in special metallographic clamps as illustrated in Figure 30. The specimen was then polished metallographically and photographed at 50X. The photographs were then measured.

Comparison of the results obtained using the above procedure with micrometer measurements revealed a difference much less than those obtained with a comparator. However, this difference (.0005 - .0001 inch) was still considered too great. It was decided that the metallographic method be used to measure only dimensions which could not be measured with a micrometer.

In an effort to obtain greater accuracy a fourth method was attempted whereby a small mold was clamped onto a portion of the tape, and filled with $\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$ solution. This solution was allowed to set for 2 hours. The impression thus produced was then projected on a comparator and measured. These measurements also did not agree (0.001 inch larger) with micrometer measurements.

External comparators, toolmakers' microscopes, and air gages, in combination, were tried next. A comparison of the dimensions obtained by this method versus those obtained by metallographic and micrometer methods is as follows:

5.4 Evaluation of Measuring Techniques (Continued)

	<u>Width</u>	<u>Height</u>	<u>Groove Depth</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
<u>"I" Beam</u>							
Non-Metallographic	.1378	.060	.0093			20°	15°
Metallographic	.1343	.0586	.0100	7°30'	6°	16°	15°30'
<u>Channel</u>							
Non-Metallographic	.2025	.0265	.0095	9°	14°		
Metallographic	.2015	.0268	.0095	7°	7°30'		

Note:

- 1 = top left side
- 2 = top right side
- 3 = bottom left side
- 4 = bottom right side

The above comparisons show that there is a large discrepancy between the two methods. More significant however, is the fact that the non-metallographic measurements do not agree with succeeding attempts to measure the same tape.

5.5 Interference Fit

It was desired to obtain a measurement of the forces involved to produce an interference fit between the "I" beam and the channel, even though the "I" beam was out of tolerance initially. The test was accomplished in the following manner: Two one inch lengths of channel were butted against each other and the "I" beam placed over the flats. Two more channels were then added to complete the top layer. The assembly was then hydraulically pressed together in a flat position. The gauge pressure was increased from 0 to 3000 psi, to 5000 psi, to 7000 psi and finally to 10,000 psi. At each pressure reading the tapes were polished, etched and photographed. Pressure was maintained on the sample at all times.

This procedure determined the force required to produce an interference fit.

5.5 Interference Fit (Continued)

A determination of the force needed to achieve an interference fit is carried out as part of evaluation of each tape lot produced. Figure 31 shows the results of pressing together the tapes shown in Figure 32. The load was applied in the center of the "I" beam. It may be noted that the center of the "I" beam has deflected before one side has had a chance to seat. This caused a cocking effect resulting in an unsatisfactory interference fit. Another set of channels and an "I" beam were pressed together with the load applied to the "I" beam flanges. The result is illustrated in Figure 33. This loading method eliminated some of the bowing and resulted in better seating of the sides. The lack of good fit is due to the undersized width of the "I" beam groove. Despite this the tapes stayed locked after the load was released.

In order to determine the amount of interference fit from the standpoint of assembled dimensions and force needed for separation, an experiment was carried out whereby the "I" beam and channel tapes shown in Figures 21 and 25 were pressed together (2 layers) and the total thickness measured (from inside of "I" beam to outside of channel) as a function of applied load. The results are given in Figure 34. It can be seen that a 2400 psi force was necessary to initiate a permanent interference fit and a 5000 psi force was necessary to seat the "I" beam on the channel. Figure 36 shows a 3 layer assembly pressed together under a 5000 psi force. Though some separation is still believed to be present, the illustration exaggerates this due to rounding of edges during polishing. This fact is confirmed by observation of strain markings adjacent to "gaps" when the assembly was subjected to higher compressive loads.

In order to estimate the force needed to overcome the interference fit, the fully seated sample was attached to small tensile machine grips by means of wires. Despite non-concentric loading, a load of 14 pounds was required to fail the 1" long assembly. Reseating of the specimen and repetition of the test resulted in a failure load of 11 lbs. A third test of the same specimen yielded a failure load of 6 pounds.

The values obtained are considered sufficient to prevent unwrapping (during vessel assembly) of a partially wrapped layer upon removal of the restraining forces imposed by the wrapping mechanism and drag break. This was verified during trial wrapping of a dummy arbor.

5.6 Tensile Testing Apparatus

All attempts to test both "I" beam and channel shaped tapes in tension have failed to give reproducible values. This is due to the fact that the tapes broke at the grips. Consequently, a rig has been designed whereby the tape is wound on a drum at each end. These drums, in turn, have plates welded to them which are held by the grips. The frictional force created by the wound tape is sufficient to prevent slippage. This apparatus has been constructed and is shown in Figure 36 (LS 25806).

5.7 Heat Treatment

The heat treat procedure was designed to produce optimum properties in both channel and "I" beam tape, keeping in mind the goal of a 250,000 psi yield strength with 4 percent ductility.

The specimens to be heat treated were first degreased and then capsulated in vacuo. Heat treatment was carried out in a furnace of constant heat zone ($\pm 50^\circ\text{F}$) for various times ranging from 5 hours to 38 hours at a given temperature. This procedure was repeated at several temperatures until the time and temperature to produce maximum properties was found. The results are presented in the following sections.

5.7.1 Channel Heat Treatment

The results of aging channel tape are presented in Table I and Figure 37. The maximum yield strength was obtained after aging at 700°F for 12.5 hours. The yield strength produced by this treatment was approximately 278 ksi while the ultimate strength was 280 ksi. The elongation was 1.5 percent in an 1" gage length. This heat treatment results in approximately the same properties as the "I" beam heat treatment.

5.7.2 "I" Beam Heat Treatment

The results of aging "I" beam tape are given in Table II and are presented in Figure 38. The maximum yield strength was obtained after aging at 750°F for 25 hours. The ultimate tensile strength produced by this treatment was approximately 279,000 psi and the yield strength was 272,000 psi. The elongation was 1.5 percent (1" gage length).

5.7.3 Metallographic and Hardness Study

The aging response of the channel tape as a function of percent reduction in area and hardness was investigated. This was accomplished by aging samples, having the cross-sections shown in Figure 27 at 750°F for 20 and 46 hours in a vacuo. The resulting microstructures are presented in Figure 39. It may be seen that these microstructures indicate behavior in a normal fashion with evidence of aging taking place at the first Turks head breakdown pass on (a) and (b). The presence of a spheroidal precipitate (probably $TiCr_2$) shown in Figure 39 (c) is indicative of overaging.

A Vickers hardness survey using a 5 kilogram load was taken across the above specimens. The results are shown in Figure 41. The curves indicate an increase in hardness with increasing reductions. The 47 hour-aged hardness is less than the hardness obtained with the 20 hour treatment.

5.8 Elimination of Twist* and Bow **

Twisting and bowing of tapes was found to cause difficulty during the wrapping operation. Twisting resulted in cocking, particularly in the case of the "I" beam, resulting in loss of interference fit. Bowing resulted in a "pre-set" helix causing difficulty during stacking, particularly in the case of the first channel layer.

Both problems are associated with the use of the bull block which supplies the force necessary to draw the tape through the Turks head. In order to eliminate bowing as well as twisting, a specially designed arrangement is being substituted for the presently used bull block.

5.9 Coefficient of Friction

The design of both channel and "I" beam shapes assumed a coefficient of static friction of 0.3-0.5. An investigation to determine the actual value was performed in the following manner:

- * Twist - Rotation of cross-section about tape axis.
- ** Bow - Bending of the tape axis parallel to the plane of the web.

5.9 Coefficient of Friction (Continued)

Two titanium channel tapes were mounted back-to-back and clamped with a predetermined load (Figure 41). The channels were then pulled in opposite directions and the load to initiate slippage noted. This experiment was repeated with different clamping loads and the corresponding slippage loads recorded. The results are tabulated in Table III.

An increase in the coefficient of static friction from .270 to .348 as a result of heat treating was observed. Analysis shows the interlock to be effective only when the condition $\tan \theta < \mu$ is satisfied, where θ is the interference fit angle, and μ the coefficient of static friction. Figure 42 shows the derived relationship between the tape angle and coefficient of friction.

5.10 Evaluation of Bonding Methods

In accordance with design requirements, it is essential that the tape be bonded to the adapters. The possibilities considered include brazing, soldering, ultrasonic welding, and the use of resins.

The goal was to obtain a tensile shear strength of 4,500 psi with 0.001" strain.

Brazing was not attempted since the temperatures involved are usually above 1000°F which is in excess of the upper limit of the aging temperature. Low temperature brazing or soldering and ultrasonic welding were found unsatisfactory. Epoxy resins appeared attractive since they are either room temperature curing or cure at slightly elevated temperatures. An evaluation was carried out wherein a piece of steel large enough to contain a piece of Bl2OVCA channel tape was zirconite blasted and degreased. The titanium tape was cleaned in 3 parts HF-30 parts HNO_3 solution for one minute and washed in water. The resin was applied to both parts which were then allowed to come in contact with each other. The specimens were pulled in uniaxial tension using self-aligning grips. A deflectometer was used to measure the cross-head movement. Bl2OVCA channel tape was previously tested and stress-strain curves determined. At given loads a corresponding strain of the tape was subtracted from the total deflection and stress-strain curves for the resins were then drawn. From these curves a modulus of elasticity for each resin was calculated.

5.10 Evaluation of Bonding Methods (Continued)

Tests showed that the resins all had modulli of elasticity in the neighborhood of 10,000 to 25,000. These results are tabulated in Table IV and are illustrated in Figure 43. It was found that Maraset (Marbellette Corporation) had the highest strength and elastic modulus while Bondmaster (Rubber and Asbestos Corporation) was next. Eastman 910 and Goodyear Plibond did not adhere. Since a value of 4,500 psi was required at a 0.001" strain, the material would require a modulus of elasticity of 4.5×10^6 . This could not be attained in resins.

5.11 Vessel Liner Evaluation

A test was carried out to determine the adherence and elastic properties of Teflon as a vessel liner. The vessel is so designed that a sharp angle exists where the first tape layer leaves the adapter. For testing purposes two (2) pieces of metal (titanium and steel) were joined together as shown in Figure 44. Teflon was then sprayed over the joint and the metal pieces pulled in tension with a 4500 pound force.

The results of this test showed that Teflon could not be relied upon to fill this corner and provide a leak-tight joint. In view of this, a modified Teflon and vinyl were tried. The results of this evaluation indicated that the modified Teflon flaked when subjected to tensile loading. However, the vinyl coating withstood the required strain (4500 lb. load) without any noticeable cracking or flaking.

5.12 Cryogenic Properties of B120VCA Ti

The results of limited low temperature tensile tests are presented in Figure 45 and shown in Figure 46.

The room temperature smooth sheet specimens had a gage length of 2-1/2" and a width of $.400 \pm .005$ ". The low temperature smooth sheet specimens were the same except that the specimen width was .250".

The notched specimens were the same as the room temperature smooth specimens, except for a notch with a root radius of $0.010 \pm .001$ ", an included angle of 45° and the minimum width was $.270 \pm .003$ ".

It can be seen from these results that this alloy is not reliable for cryogenic vessels, the notched-to-unnotched tensile strength ratios being 0.34 at -320°F.

Tests run on a second heat and a 0.050" gage thickness produced the same results.

CHANNEL BREAKDOWN

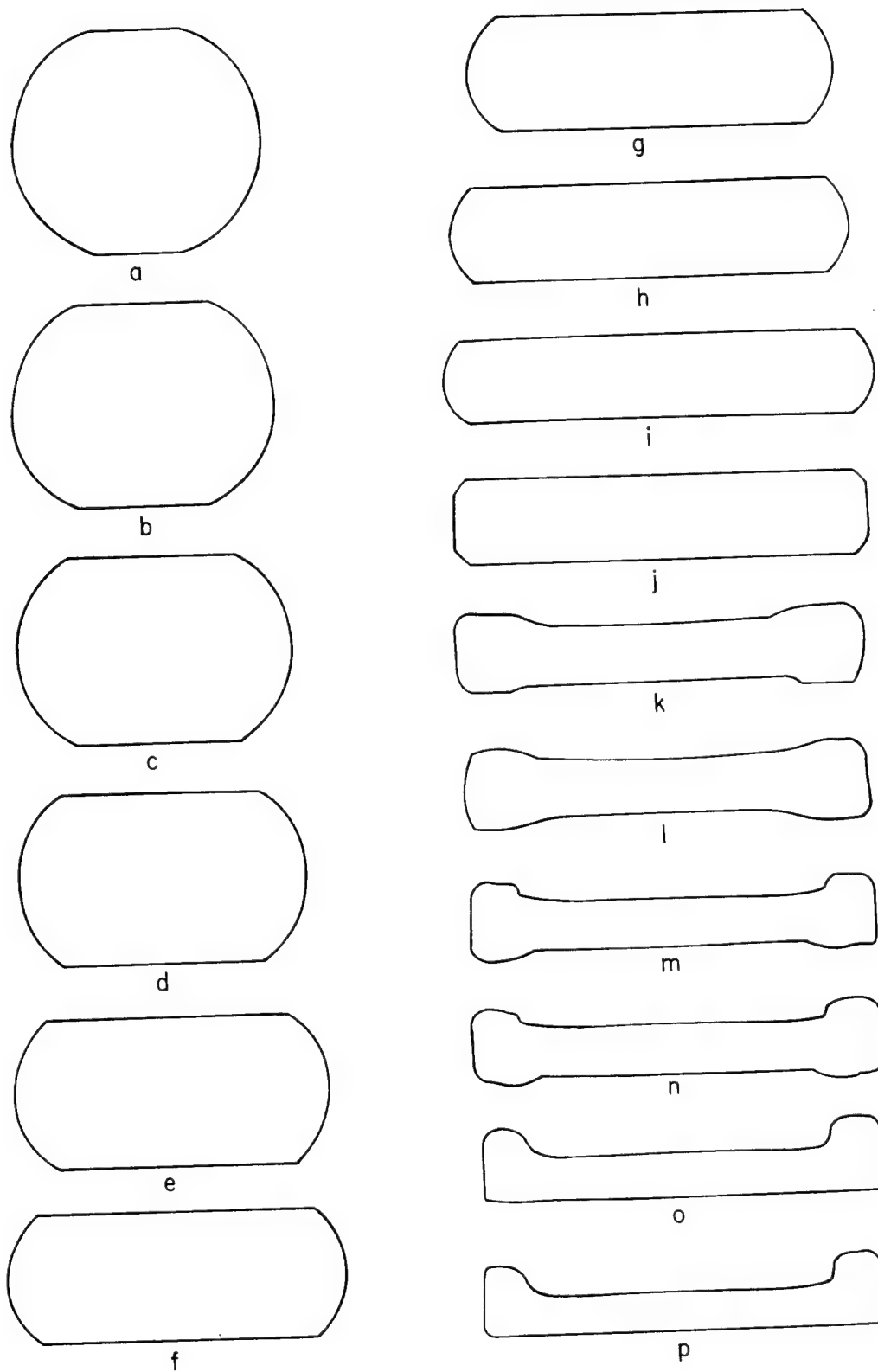
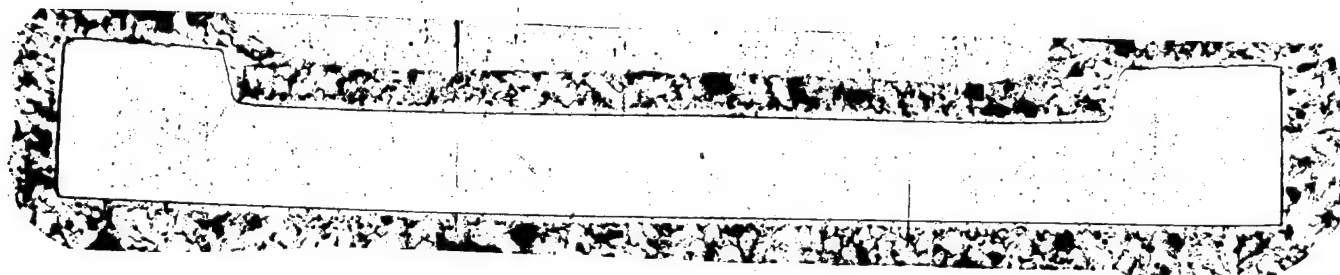
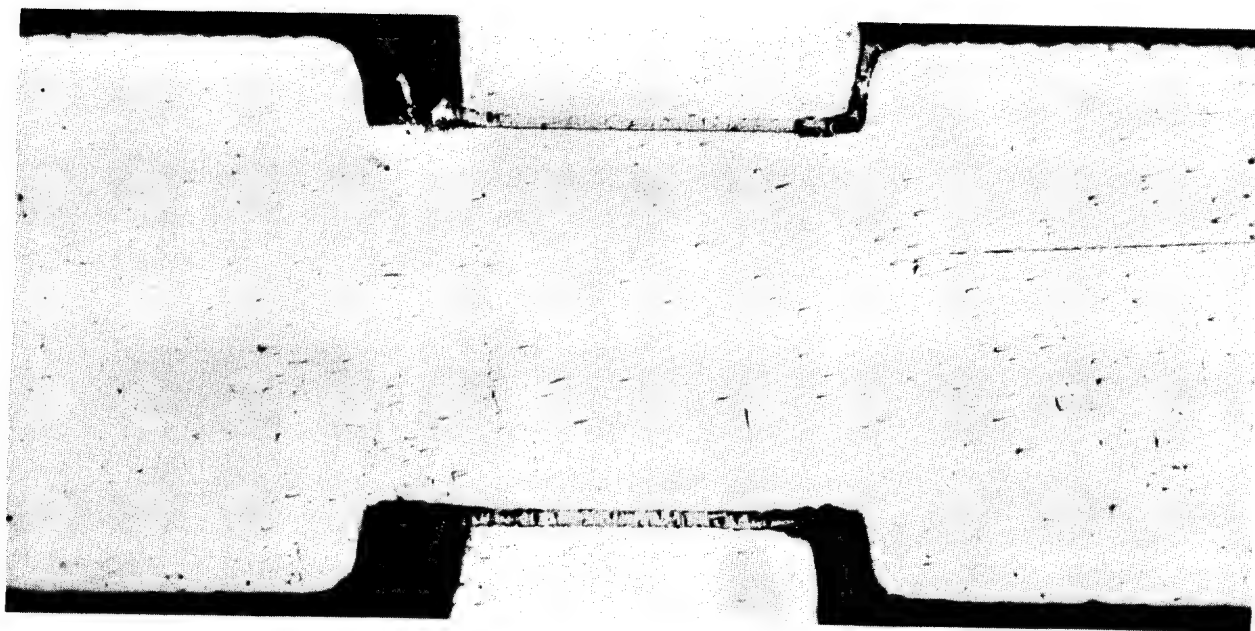
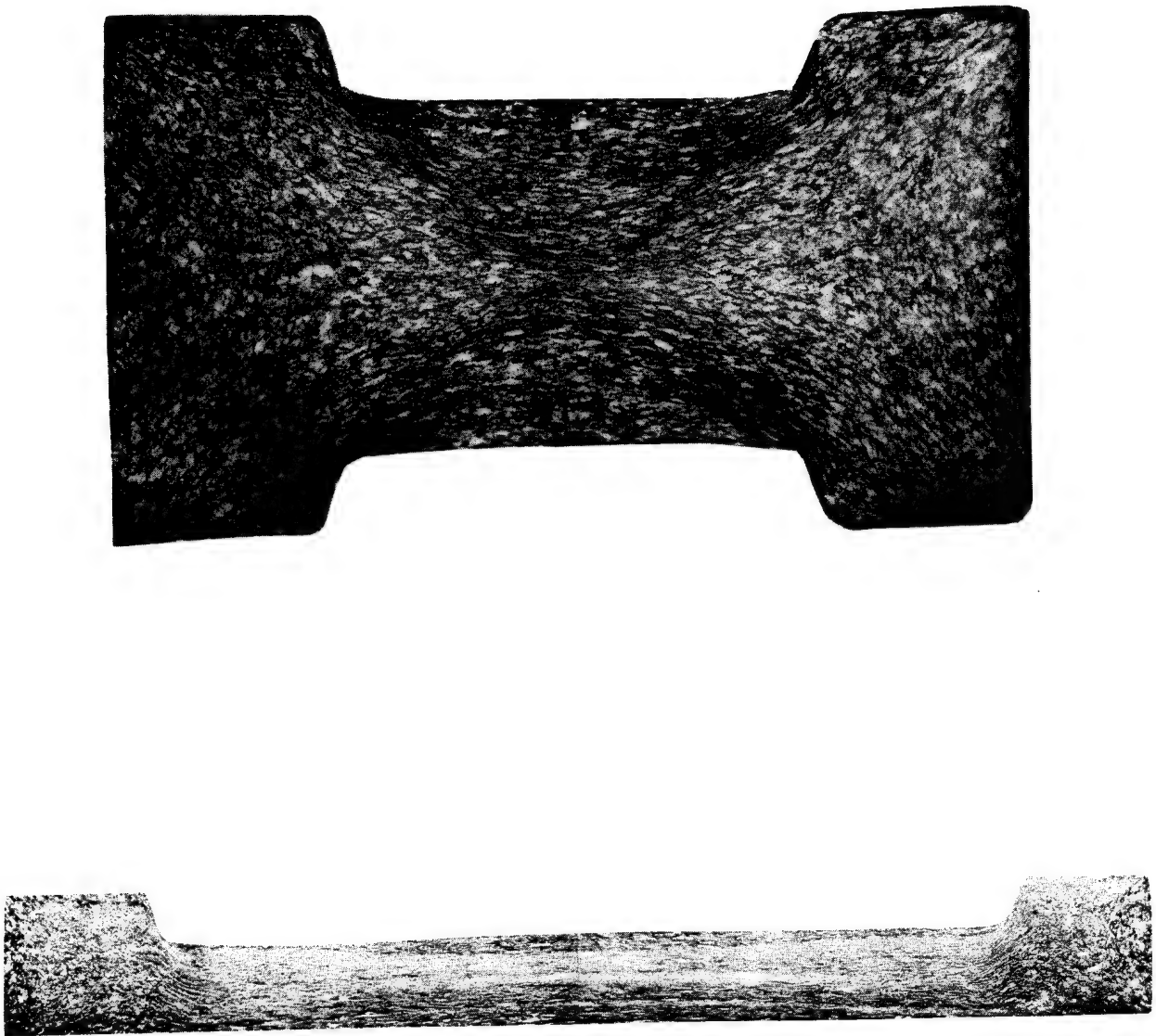


Figure 27
49

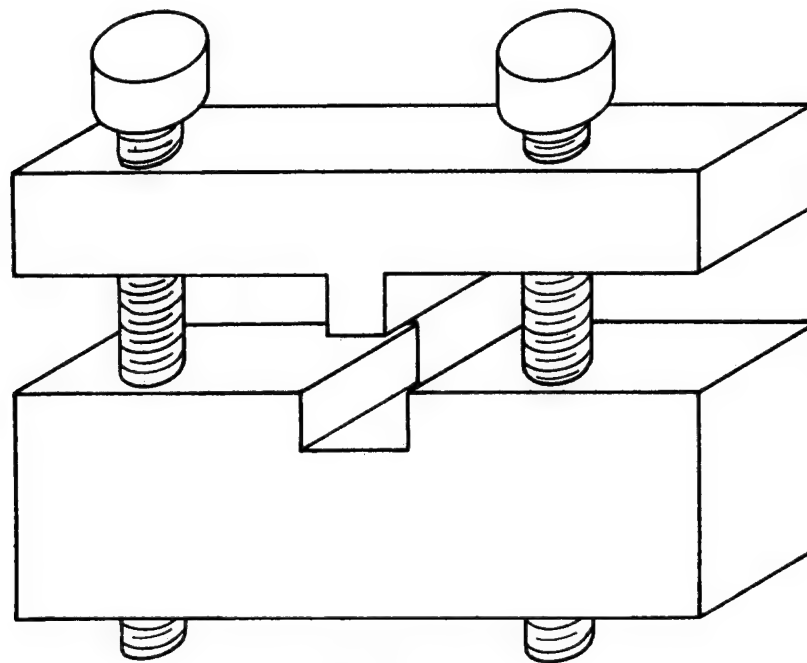


Specimens Mounted for Measurement

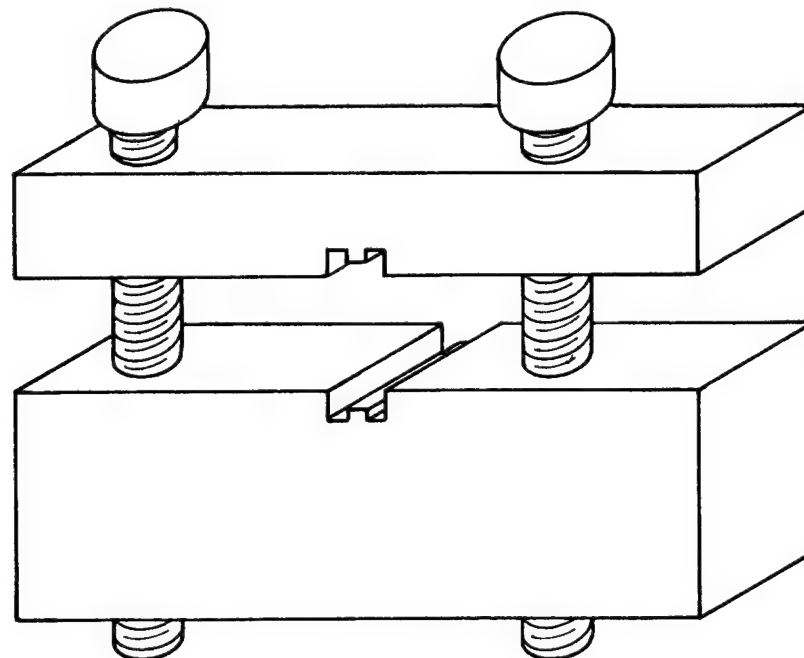


"I"-Beam and Channel Flow Lines

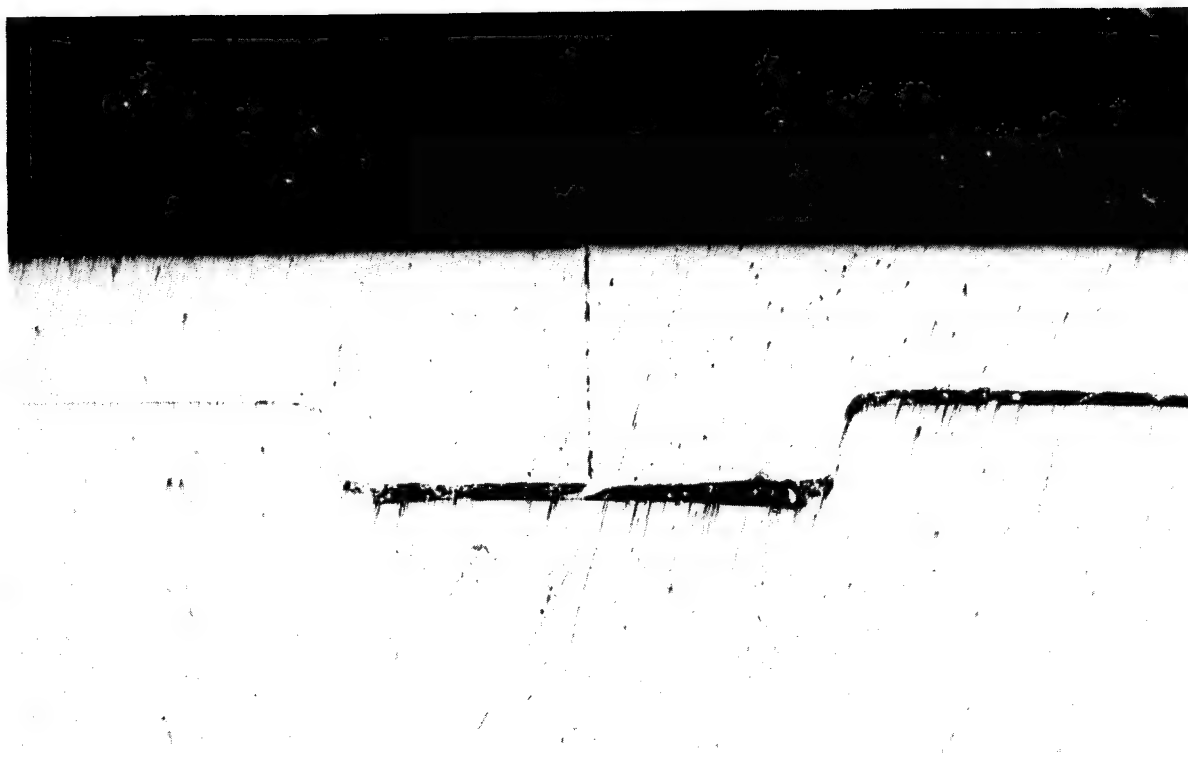
SCHEMATIC ILLUSTRATION OF METALLOGRAPHIC CLAMPS



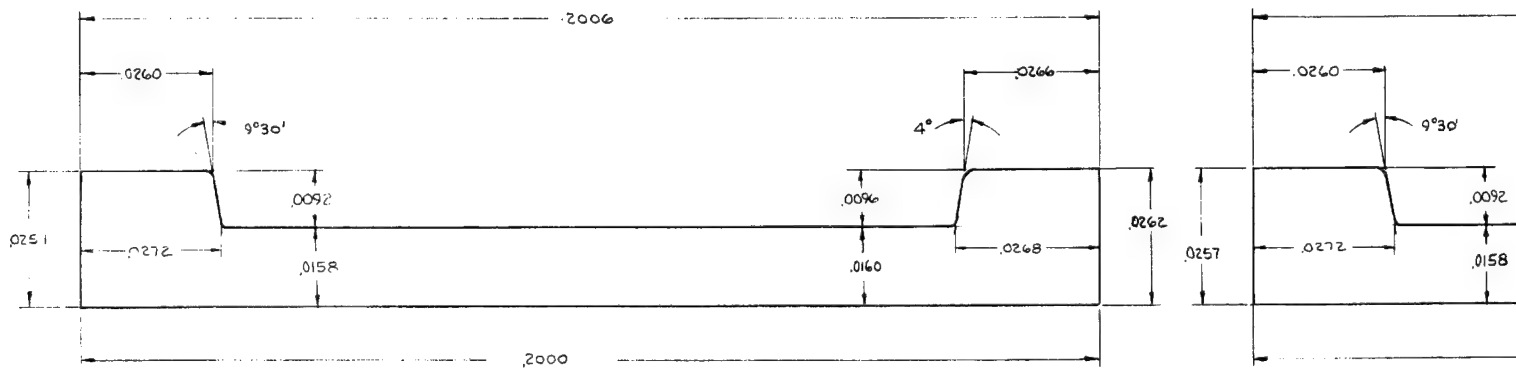
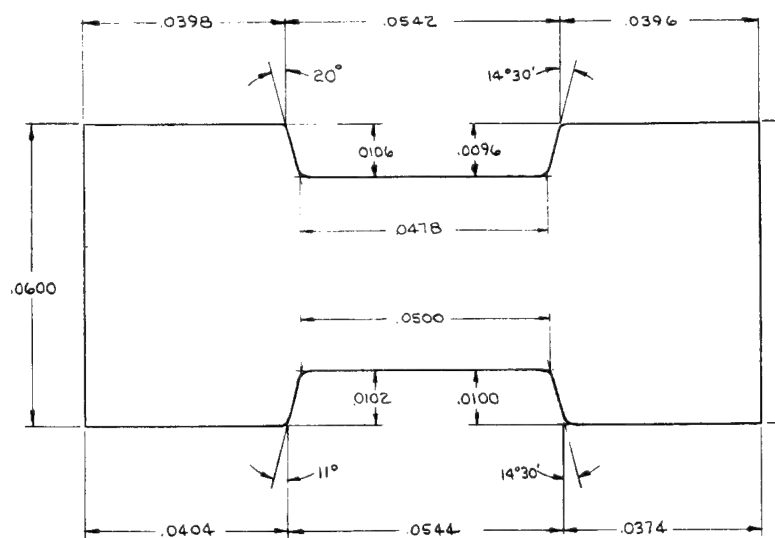
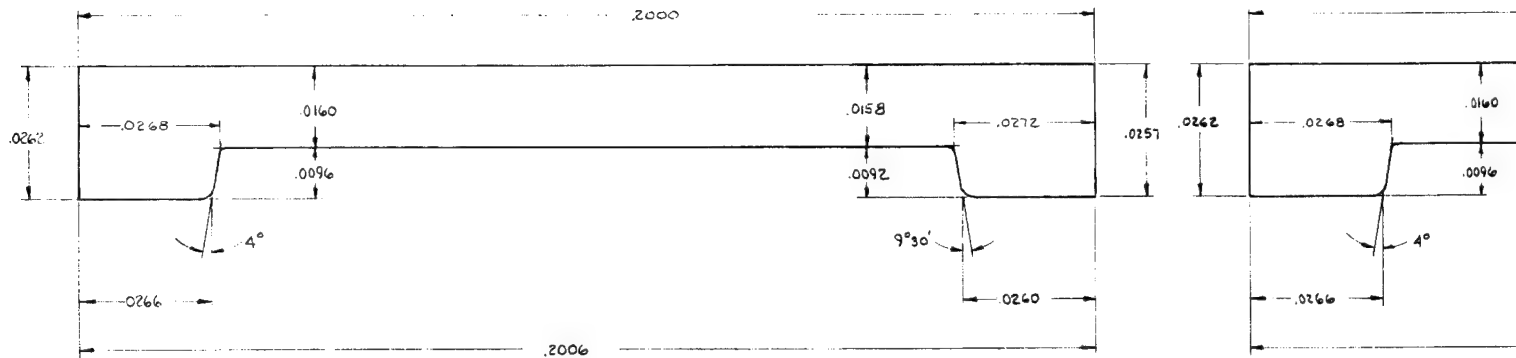
CHANNEL

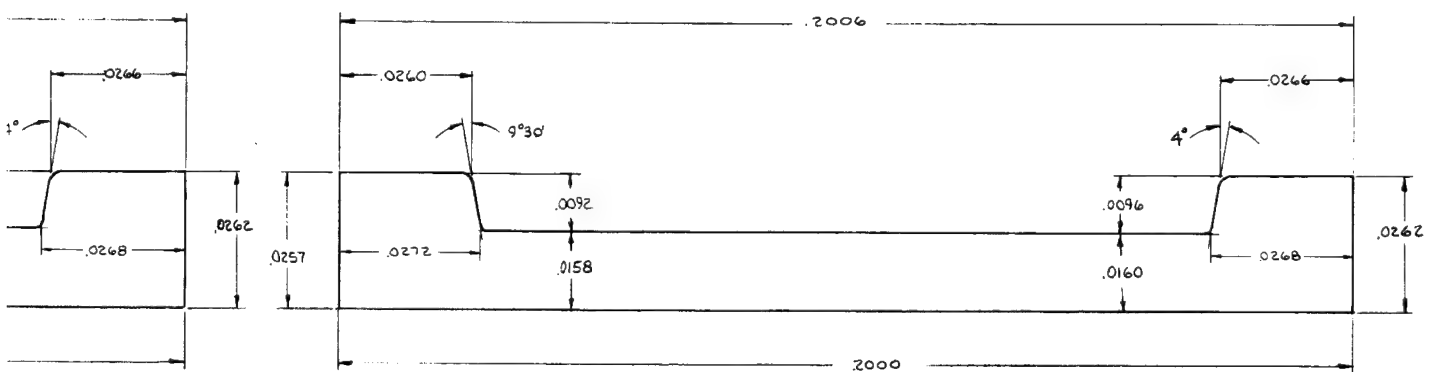
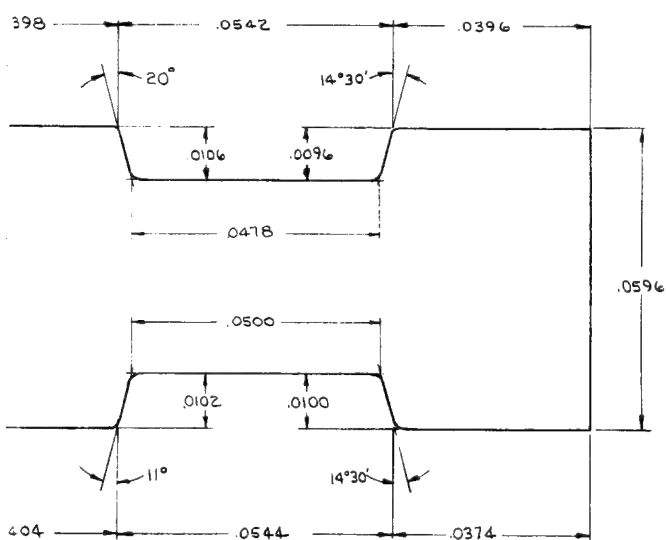
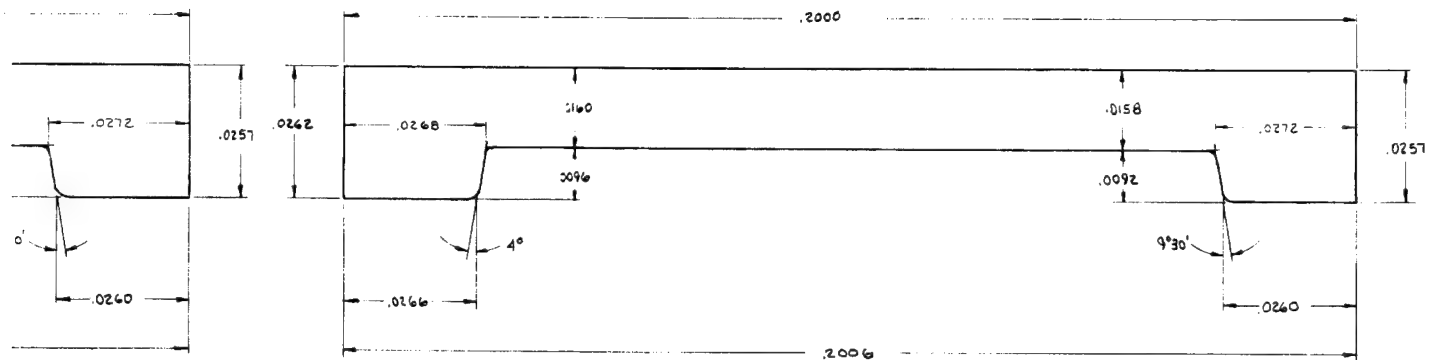


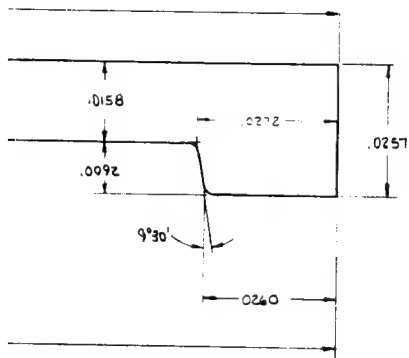
"I" BEAM



"I"-Beam - Channel - Pressed







DATE -

DUMBBELL LOAD
CHANNEL LOAD
YIELD STRENGTH

LBS.
LBS.
PS.I.

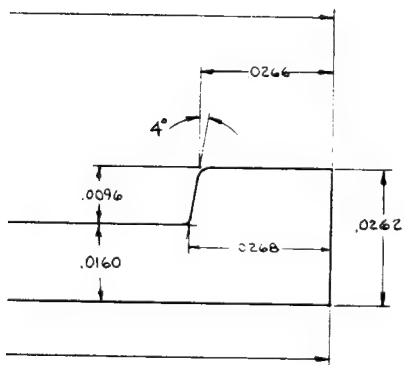
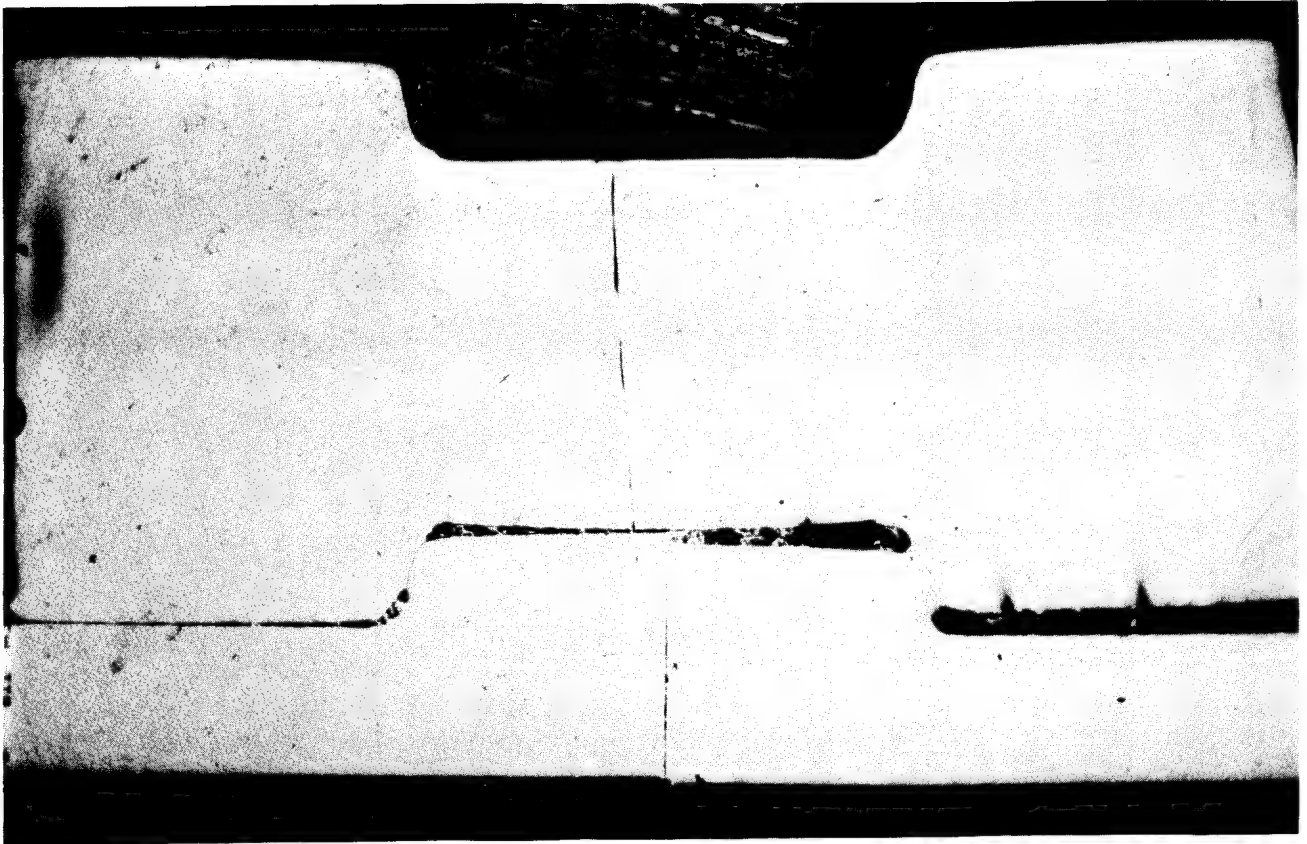


Figure 32



"I"-Beam - Channel - Pressed

DEGREE OF INTERFERENCE FIT

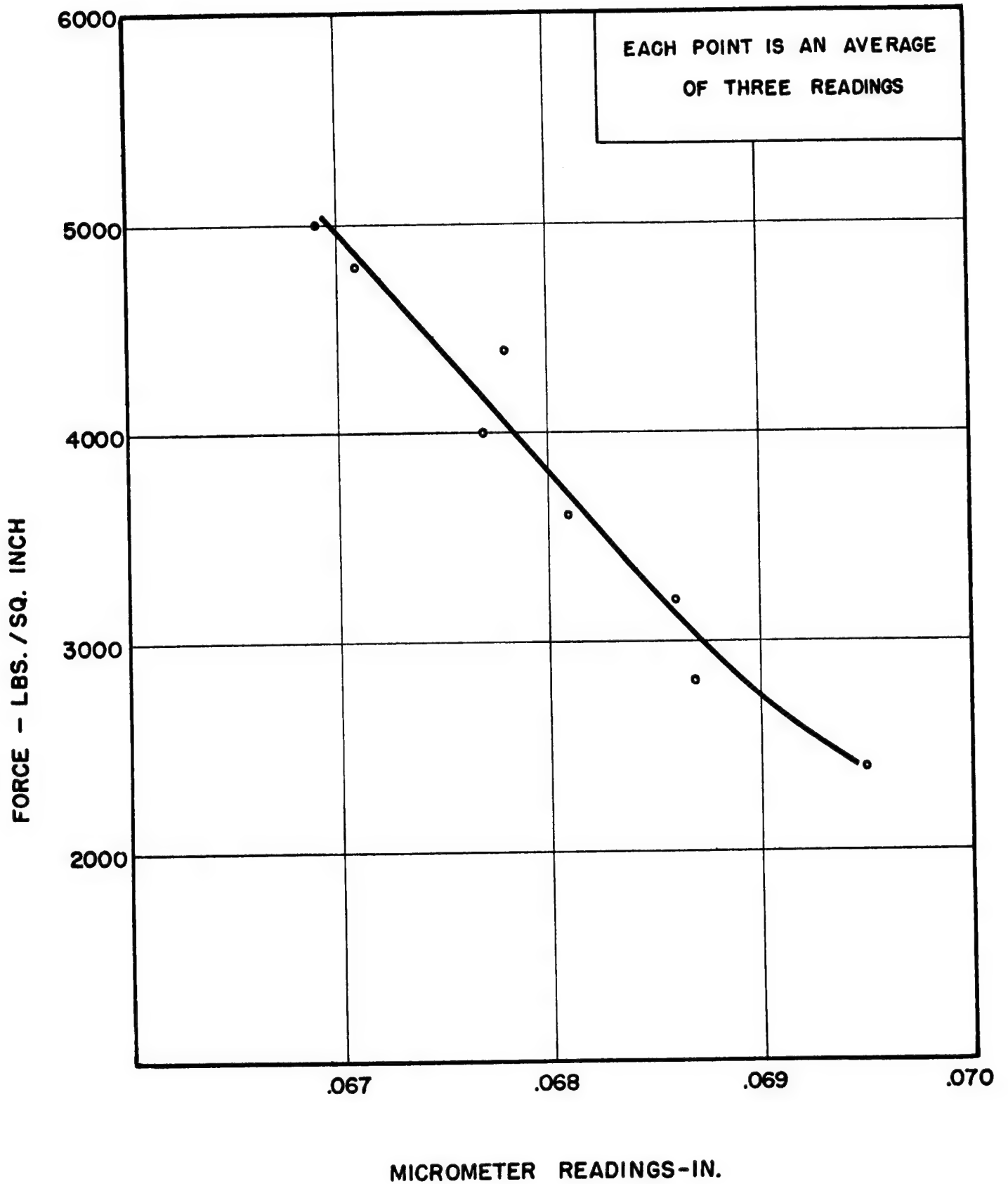
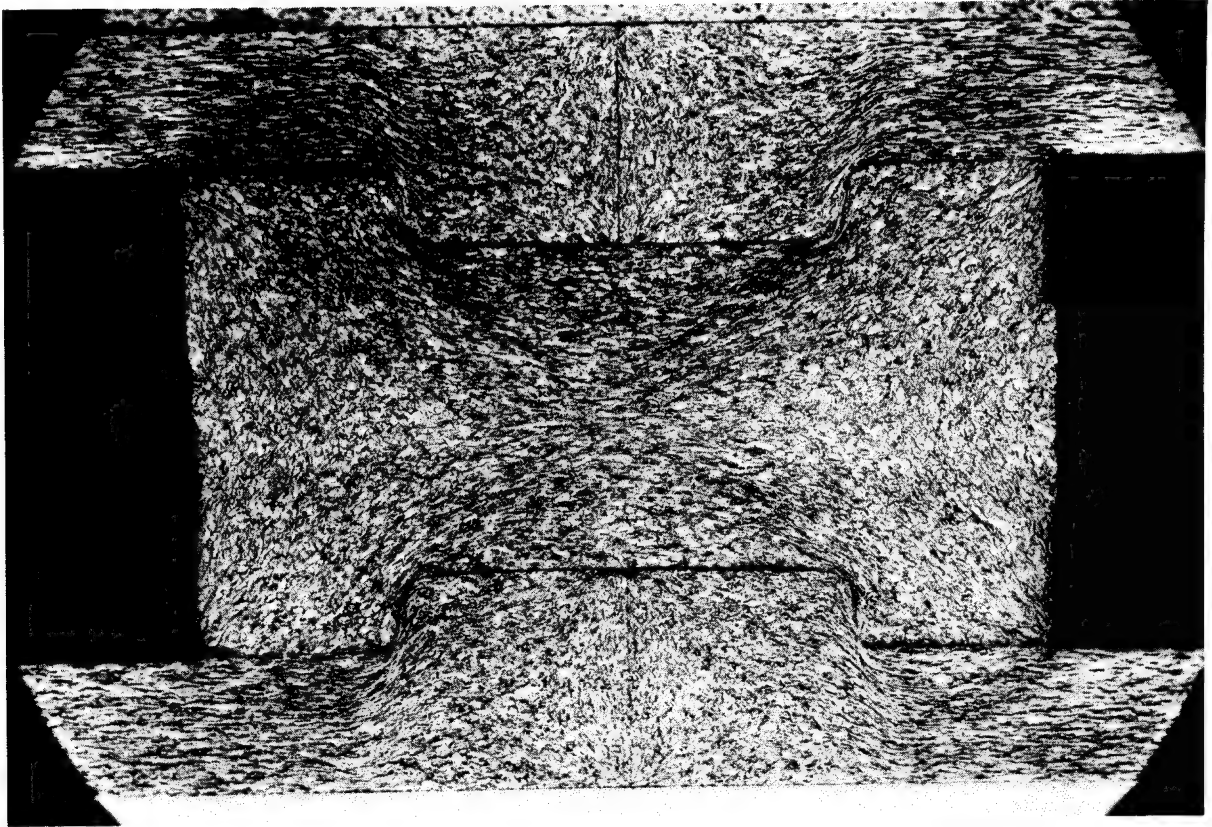
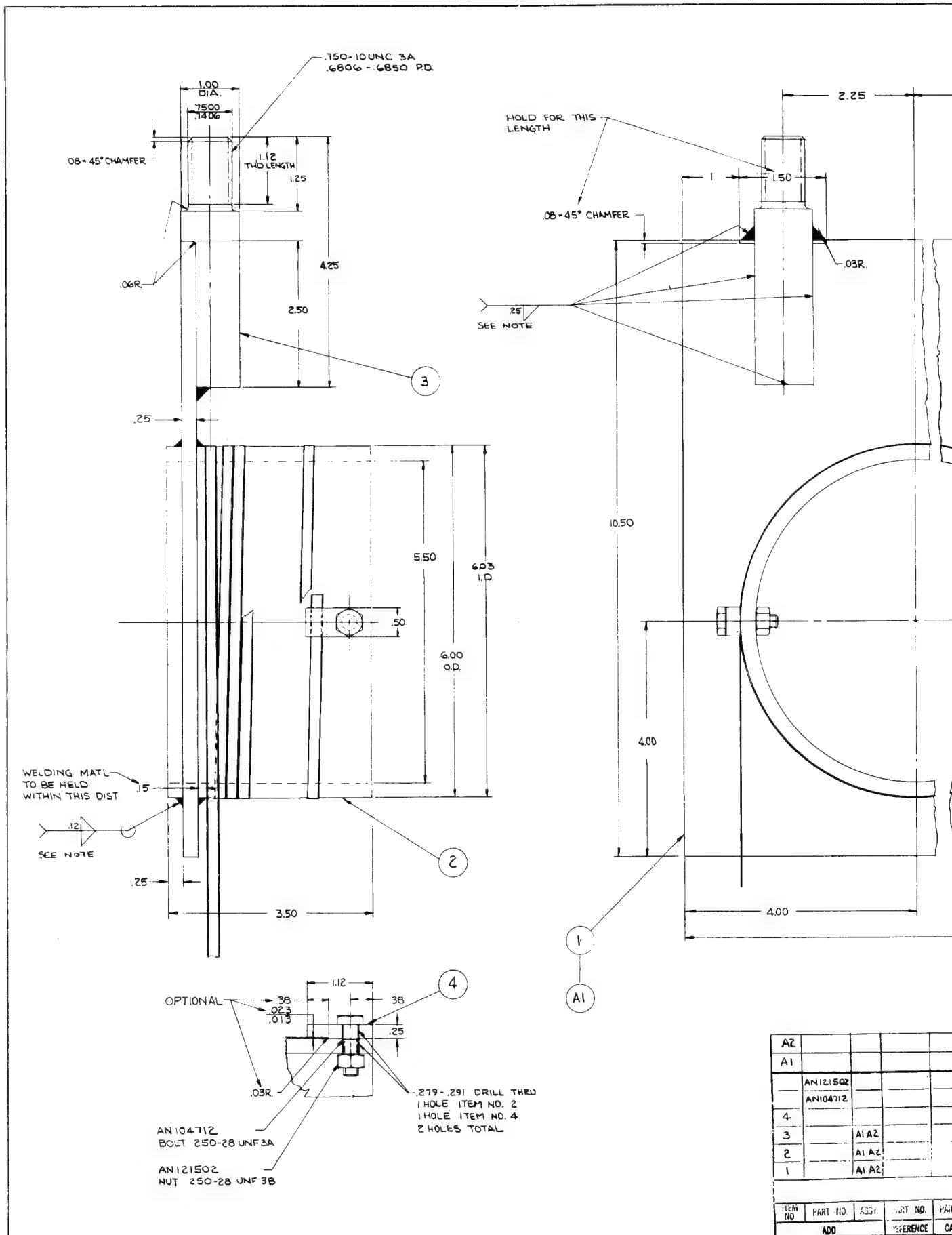


Figure 34
56

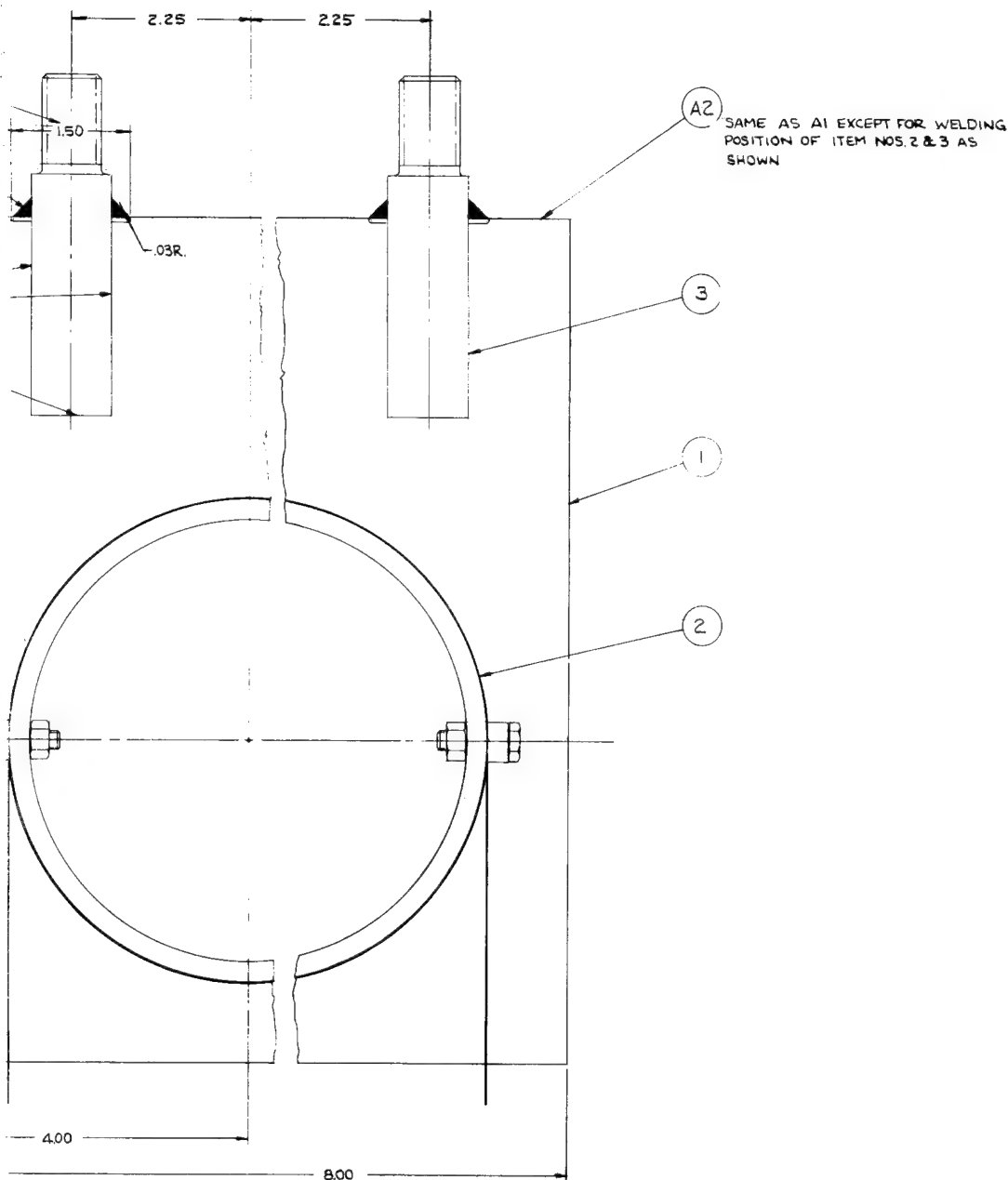


Three Layer Interference Fit



ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.
A2				
A1				
	AN121502			
	AN104712			
4				
3		A1 A2		
2		A1 A2		
1		A1 A2		
ADD		REFERENCE		CAI

REVISIONS	
CHG LTR	DESCRIPTION



LS

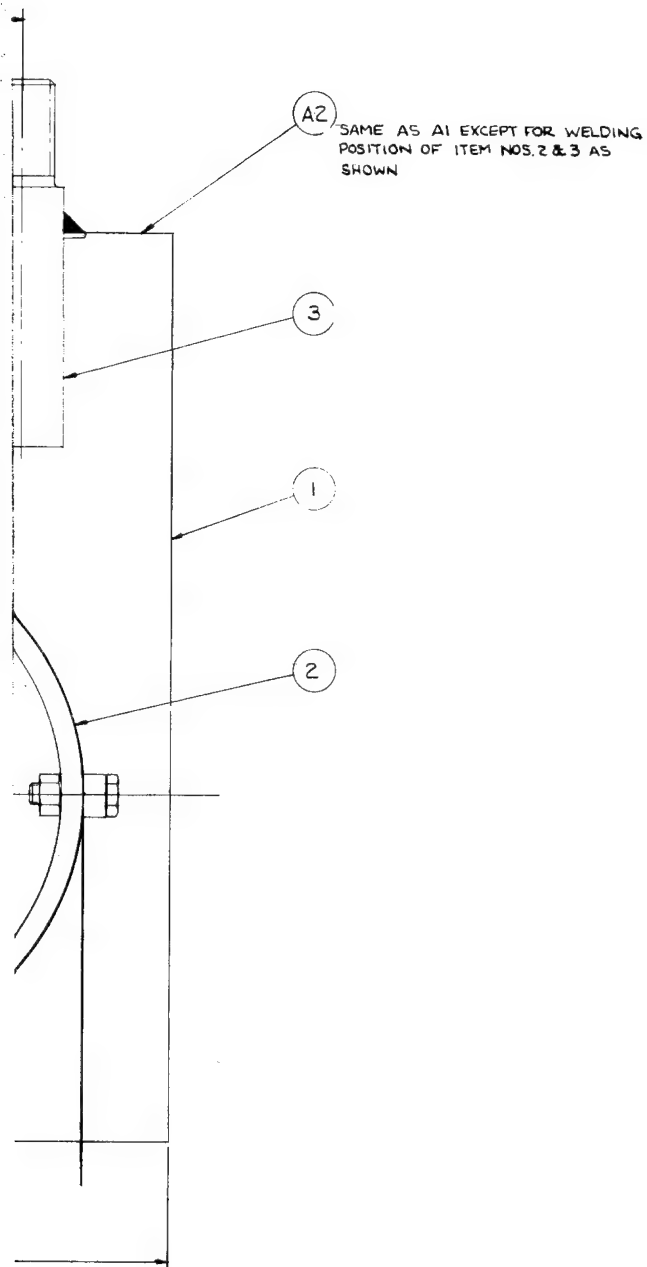
USE SPEC 8178 WELDING WIRE
 BREAK SHARP EDGES .005-.015
 APPROX R & BLEND
 WELD SIZE & LOC DIM. $\pm .030$
 FINISHED DIM. $\pm .010$
 ALL ANGLES $\pm 2^\circ$
 ALL NOTES APPLY
 UNLESS OTHERWISE SPECIFIED

A2					1	RIG ASS'Y					
A1					1	RIG ASS'Y					
	AN121502				2	NUT - .250-28 UNF3B					
	AN104712				2	BOLT - .250-28 UNF3A -.815 LENGTH					
4					2	FASTENER -					
3		A1 A2			2	LOG -					
2		A1 A2			2	CYLINDER -					
1		A1 A2			2	PLATE -					

ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.	QUAN.	DESCRIPTION	INTERC.	MATL.	OTHER SPECS	FORG CAST	WR
ADD			REFERENCE	CANCEL							

ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.	DESCRIPTION	INTERC.	MATL.
ADD			REFERENCE	CANCEL			
SCALE FULL					DESIGNED BY: <i>Emmons</i>	J. L.	
JOB NUMBER 7491					STARTED 10-24-60	10-26-60	
					COMPLETED 10-28-60		
CURTISS-WRIGHT CORP.					INTER-LOCKING TITANIUM WIRE CASE - TENSION RIG		
WRIGHT AERONAUTICAL CO.					WOODRIDGE, N.Y. U.S.A.		
					13		

REVISIONS			
CHG LTR	DESCRIPTION	DATE	ENGRS.



LS 25806

USE SPEC 8118 WELDING WIRE
 BREAK SHARP EDGES .005-.015
 APPROX R & BLEND
 WELD SIZE & LOC DIM. $\pm .030$
 FINISHED DIM. $\pm .010$
 ALL ANGLES $\pm 2^\circ$
 ALL NOTES APPLY
 UNLESS OTHERWISE SPECIFIED

SY				
SY				
260-28 UNF3B				
250-28 UNF3A - .815 LENGTH				
ER -	AISI 321			
	AISI 321			
ER -	AISI 321			
	AISI 321			

ITEM NO.	PART NO.	ASSY	PART NO.	DESCRIPTION	INTER	MATL	OTHER SPECS	FORG CAST W.R.
ADD	REFERENCE	STANDARD		PARTS LIST				
SCALE FULL	STARTED 10-24-60	COMPLETED 10-28-60	DESIGNED BY ZIMONSKI	10-26-60				
JOB NUMBER 7491								
CURTISS-WRIGHT CO.				INTER-LOCKING TITANIUM		1325806		
WRIGHT AERONAUTICAL DIV				WIRE CASE - TENSION RIG				
WOODBRIDGE, NEW JERSEY, U.S.A.								
DESCRIPTION				INTER		MATERIAL		OTHER SPECS
FORG CAST				WR				

Figure 36
 58 Tension Test Rig

TABLE I
AGING RESPONSE OF B120VCA TITANIUM WIRE
ROOM TEMPERATURE TENSILE PROPERTIES OF "CHANNEL" WIRE

Aging Condition	Ultimate Tensile Strength		Yield Strength (.2% Offset)		Elongation in 1"	
	Avg. KSI	Range KSI	Avg. KSI	Range KSI	Avg. %	Range %
As rec'd. 0 hrs.	222.7	221.2-224.2	217.0	215.9-218.1	2.5	2.0-3.0
7000°F 10 hrs.	269.0	**267.4-271.0	268.7	***268.5-269.1	1.5	1.5
7000°F 15 hrs.	275.9	**274.9-276.9	275.0	***274.4-275.8	1.0	1.0
7000°F 20 hrs.	271.5	265.2-277.2	270.0	264.6-275.2	2.0	2.0
7000°F 25 hrs.	-	**278.8	-	***280.2	0.75	0.5-1.0
7000°F 30 hrs.	291.2	***286.0-296.4	290.0	286.0-293.9	0.75	0.5-1.0
7500°F 5 hrs.	265.3	264.9-265.7	262.7	262.4-263.0	1.5	1.0-2.0
7500°F 10 hrs.	277.7	277.7	273.8	273.8	1.5	1.5
7500°F 15 hrs.	276.2	271.6-280.8	274.5	271.0-278.0	1.0	1.0
7500°F 20 hrs.	***					
7500°F 25 hrs.	-	**287.2	-	***289.4		0.75
7500°F 30 hrs.	-	**283.6	-	***293.9	1.0	1.0

TABLE I (Continued)

Aging Condition	Ultimate Tensile Strength		Yield Strength (.2% Offset)		Elongation in 1"	
	Avg. KSI	Range KSI	Avg. KSI	Range KSI	Avg. %	Range %
750°F	-	**291.1	-	***294.7	0.75	0.5-1.0
800°F	275.9	273.5-279.7	275.0	274.6-275.5	0.75	0.5-1.0
800°F	283.0	280.2-285.8	280.5	279.7-281.3	0.75	0.5-1.0
800°F	269.8	**268.8-270.8	275.0	***274.4-275.8	0.5	0.5
800°F	271.0	271.0	269.1	269.1	1.0	0.5-1.5
800°F	***					

NOTE:

* All wire samples cooled to room temperature in vacuum.

** Sample failed at listed strength which is related to yield strength.

*** Extrapolated value of the yield strength.

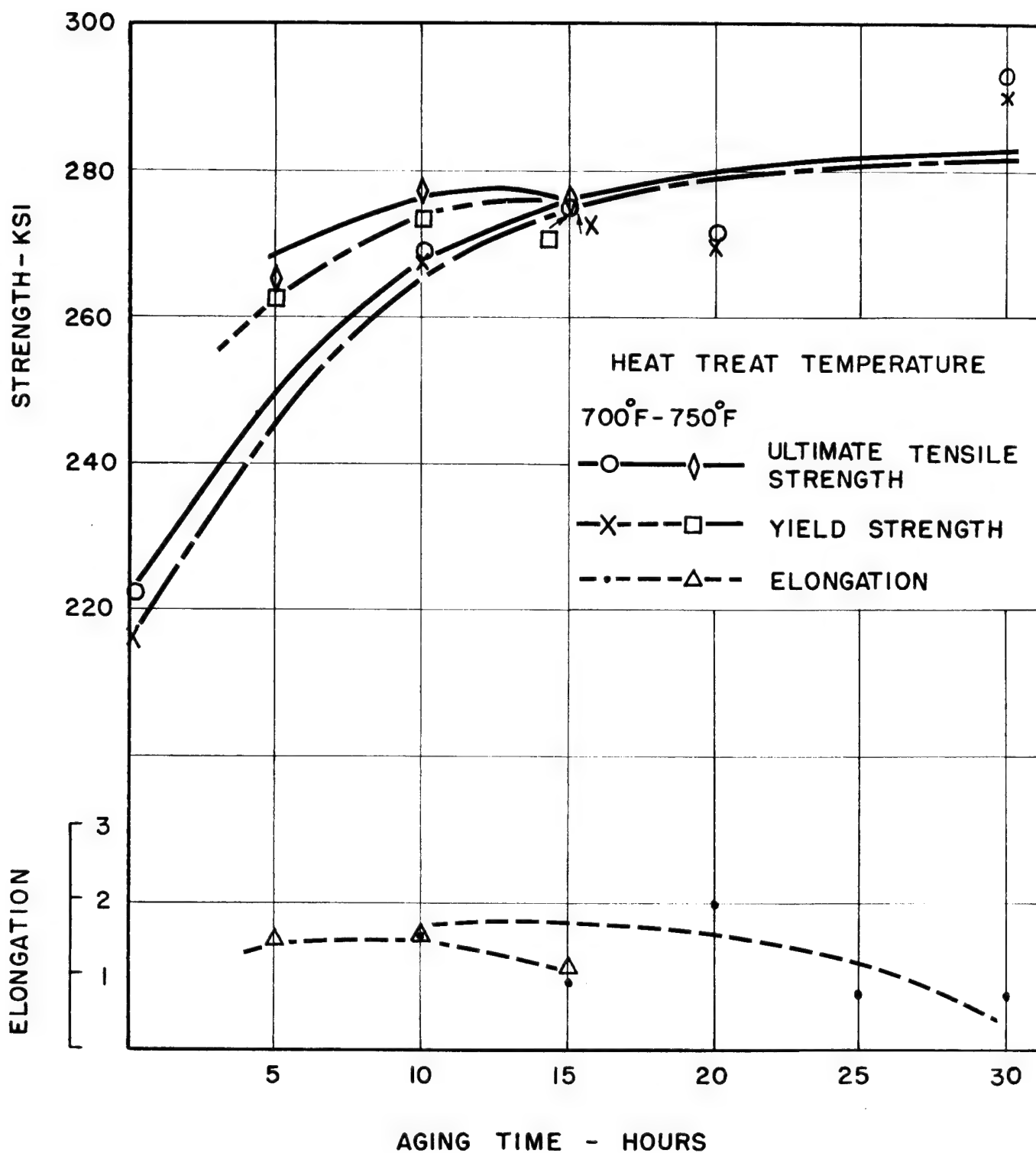


Figure 37
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TABLE II

"I" BEAM SHAPE HAVING CROSS-SECTIONAL AREA = $5.0 \times 10^{-3} \text{IN}^2$

<u>Aging Temperature and Time</u>	<u>U.T.S. (ksi)</u>	<u>Y.S. (ksi)</u>	<u>Elongation in 1" (%)</u>
As Received (50% cold work)	211.3	204.2	4.0
800°F - 5 hours	246.2	239.75	2.0
800°F - 10 hours	262.5	252.5	2.25
800°F - 15 hours	265.0	254.0	1.75
800°F - 20 hours	263.0	255.5	1.0
800°F - 25 hours	264.0	259.0	--
800°F - 30 hours	263.0	254.5	--
800°F - 38 hours	255.0	--	--

HEAT TREAT RESPONSE OF "I" BEAM WIRE

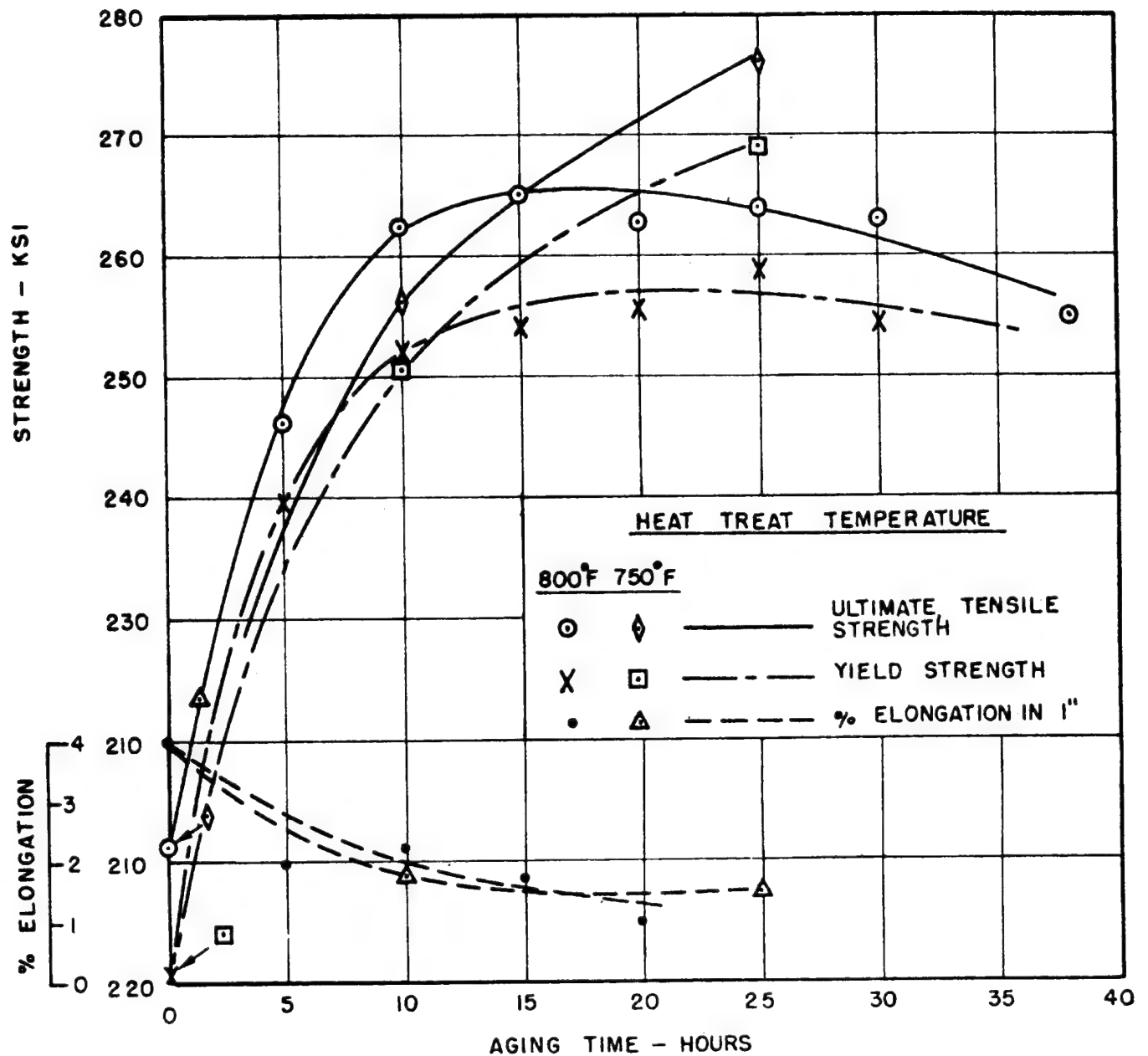
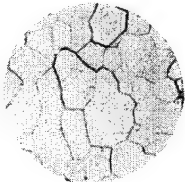
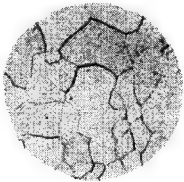
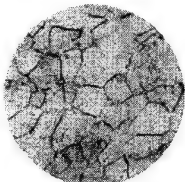
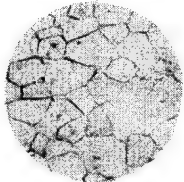
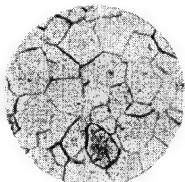
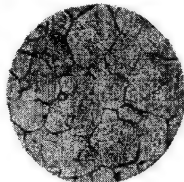
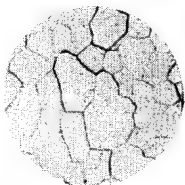
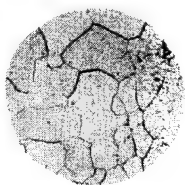
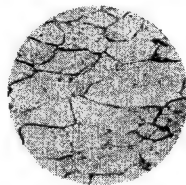
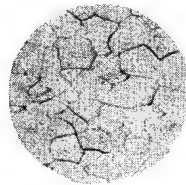
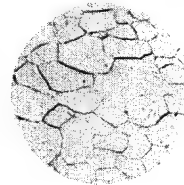
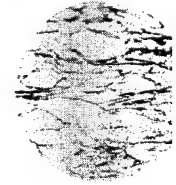
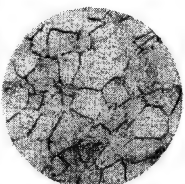
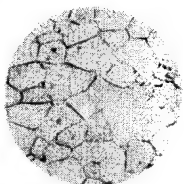
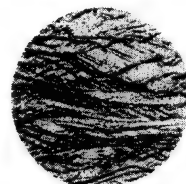
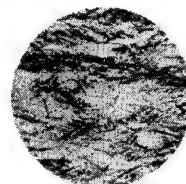
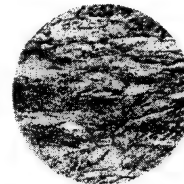
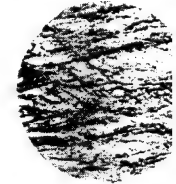
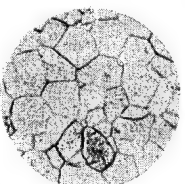

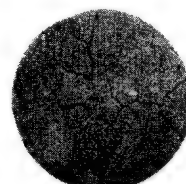
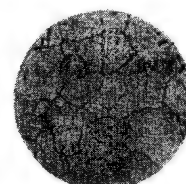
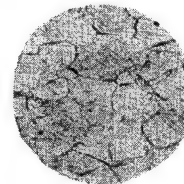
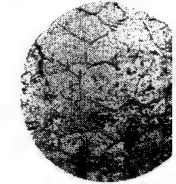


Figure 38
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AGING R

MATERIAL CONDITION		
	5.6	5.6
^a AS COLD ROLLED		
^b AGED 750°F-20 HRS.		
^c AGED 750°F-47 HRS.		

AGING RESPONSE VS. % RA

RA (%)					
5.6	5.6	11.8	18.9	25.6	30.0
					
					
					

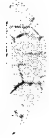
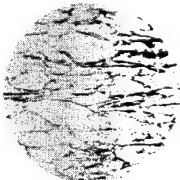

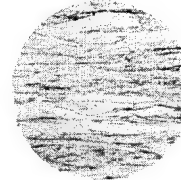
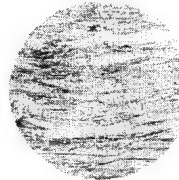

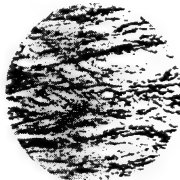
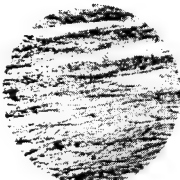
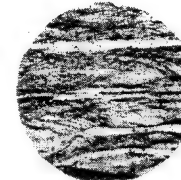
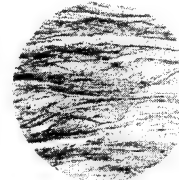

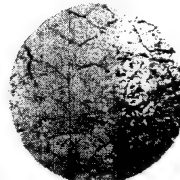
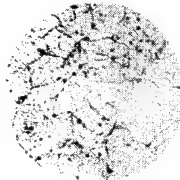
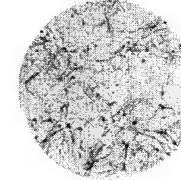
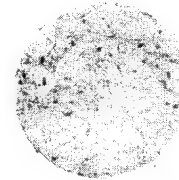
%				
3	30.0	43.3	53.3	62.8
				
				
				

Figure 39

Hardness vs % RA
(750°F Isotherm)

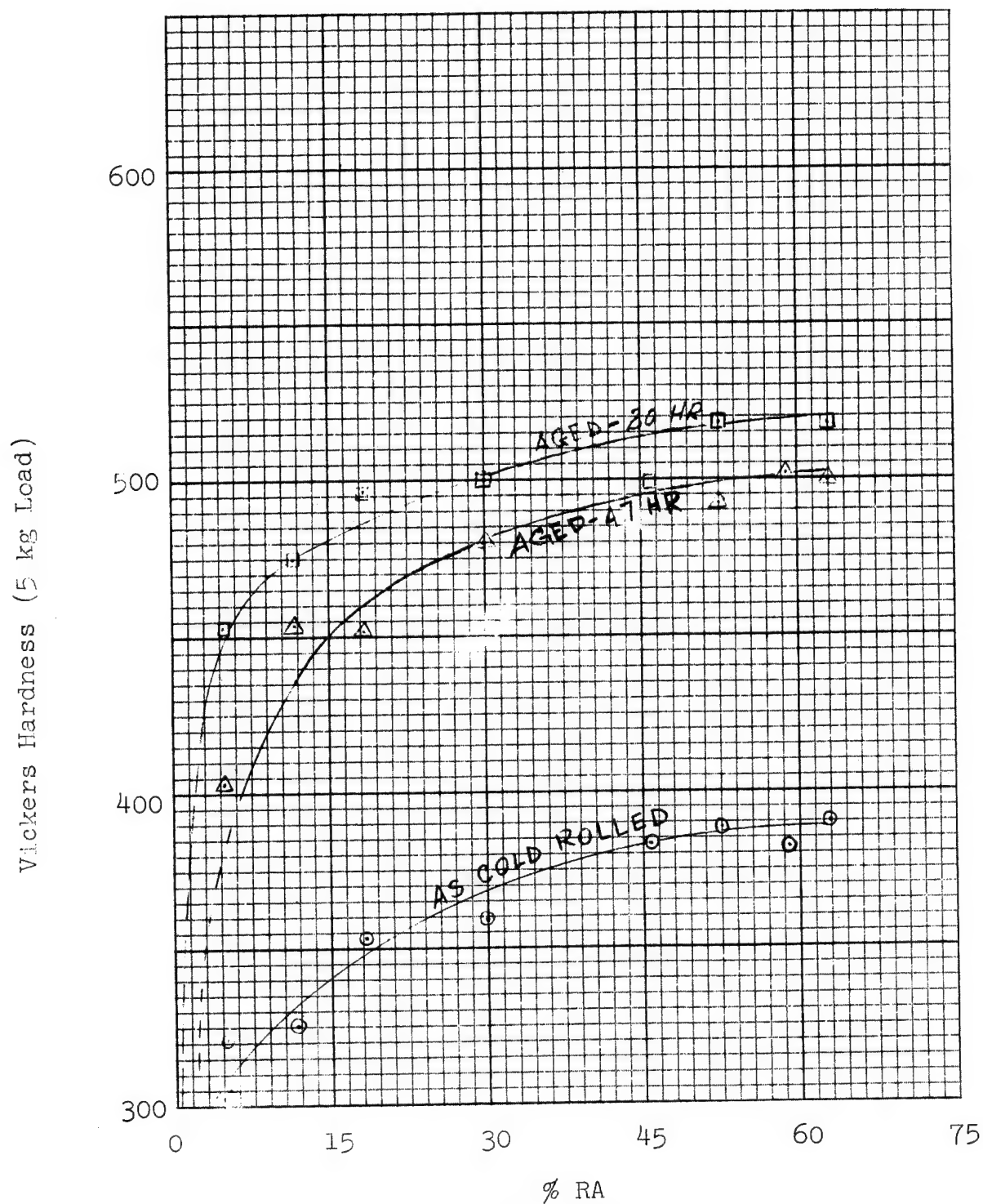
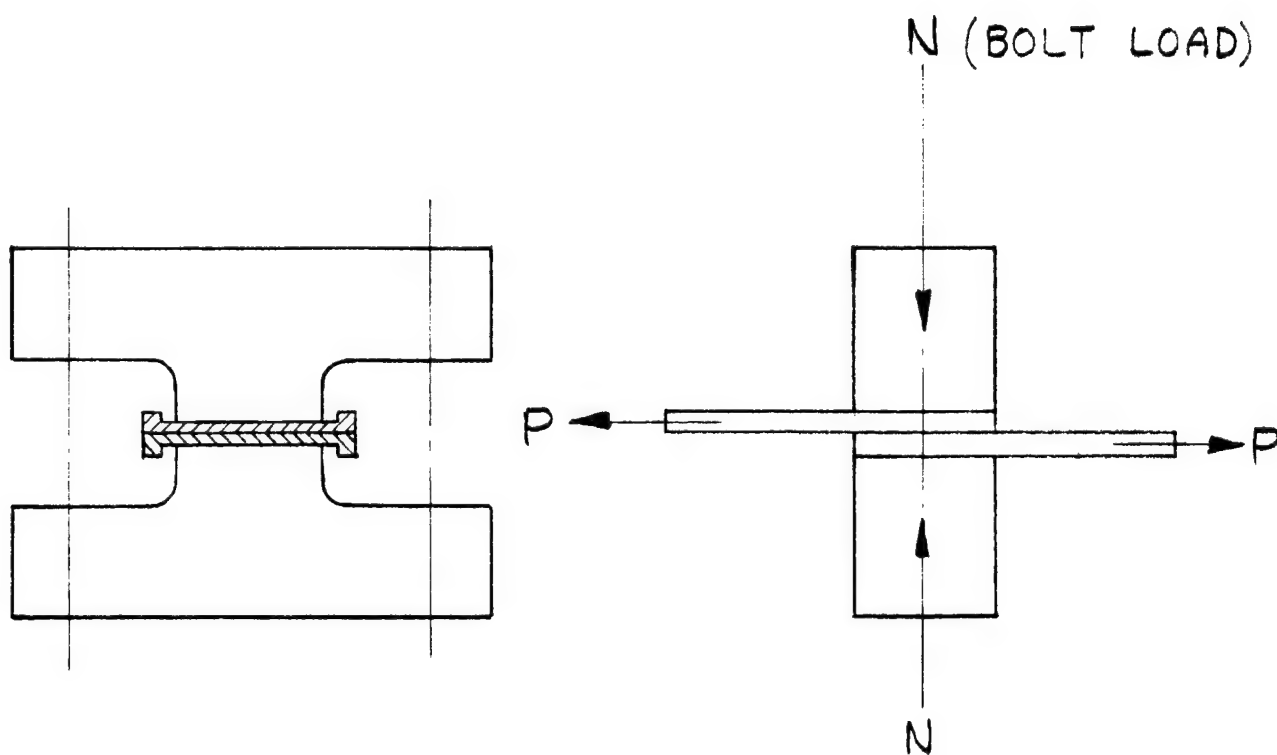


Fig. 40

FRICTION TEST CLAMP



$$\mu = \frac{P}{N}$$

Figure 41
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TABLE III

COEFFICIENT OF FRICTION OF B12OVCA TITANIUM WIRE

Torque (#)	Nominal Load N (#)	Tensile Load P (#)	Coefficient $\mu = \frac{F}{N}$
---------------	-----------------------	-----------------------	------------------------------------

Cold Rolled (Drawn) Wire

24	1046.9	280	0.267
28	1219.9	360	0.295
34	1480.0	400	0.270
42	1828.2	455	0.249
56	2436.5	660	$\frac{0.271}{0.270}$ Avg.

Cold Rolled, Heat Treated Wire

24	1046.9	395	0.377
28	1219.9	415	0.340
34	1480.0	510	0.345
42	1828.2	650	0.355
56	2436.5	790	$\frac{0.324}{0.348}$ Avg.

RELATIONSHIP BETWEEN THE ANGLE OF WIRE AND COEFFICIENT OF FRICTION

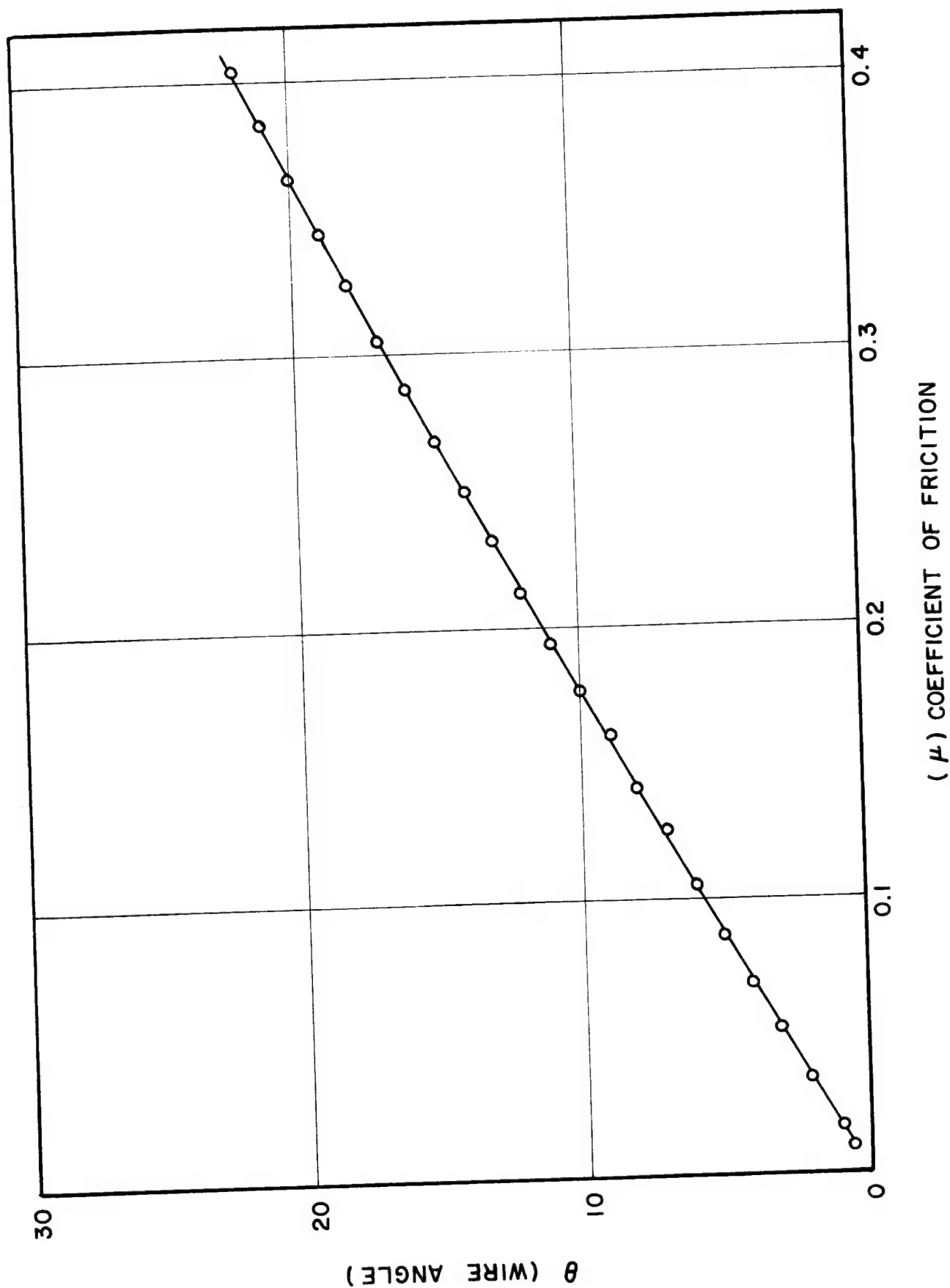


Figure 42
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TABLE IV

RESIN EVALUATION

<u>Resin</u>	<u>Shearing Stress (psi)</u>	<u>Modulus of Elasticity ($\times 10^4$)(psi)</u>
"MARASET" (Marbelette Corp.)	1003	2.04
"BOND MASTER" (Rubber & Asbestos Corp.)	824	1.78
"DEVCON '2 TON'" (Devcon Corp.)	516	1.69

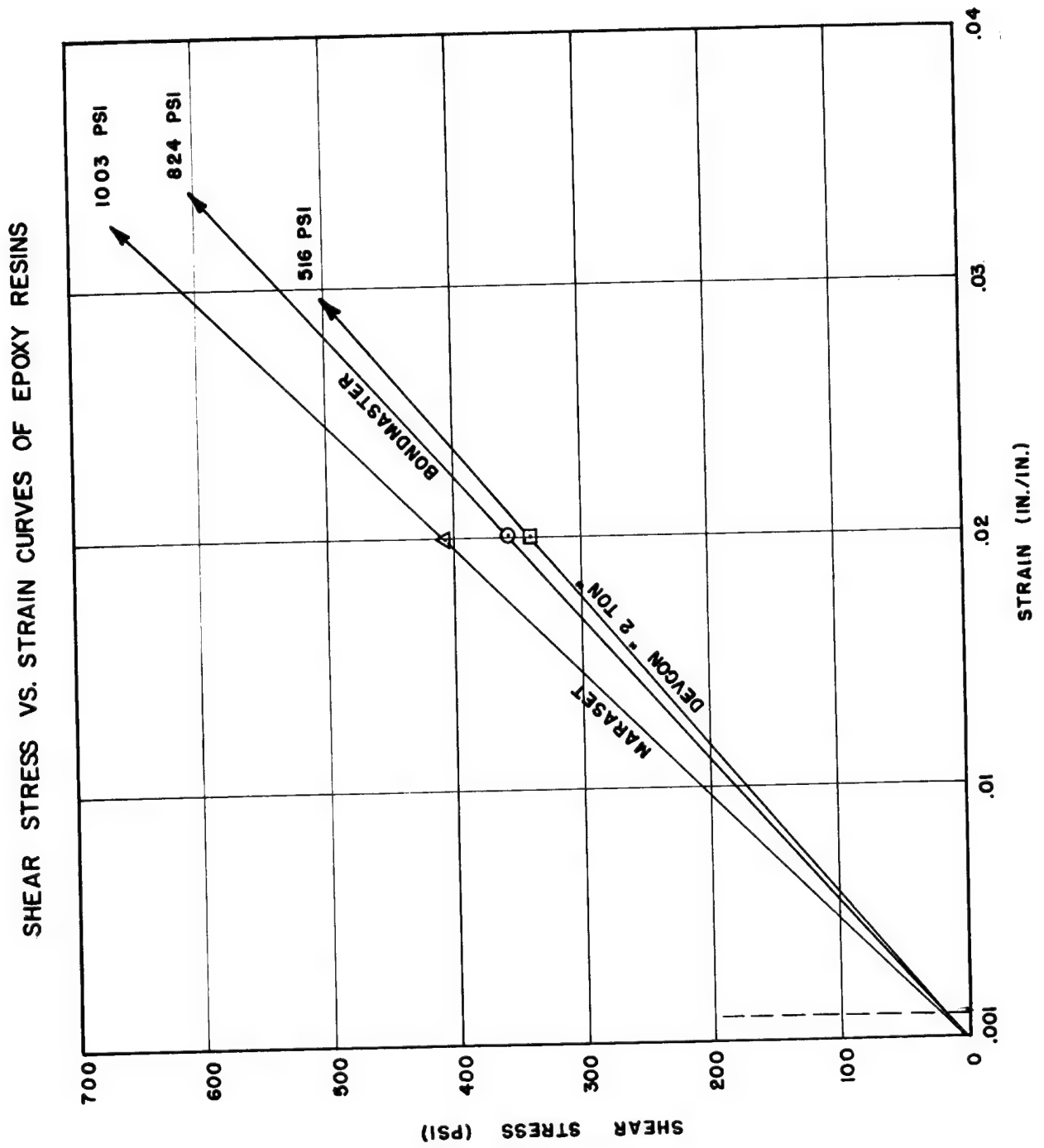
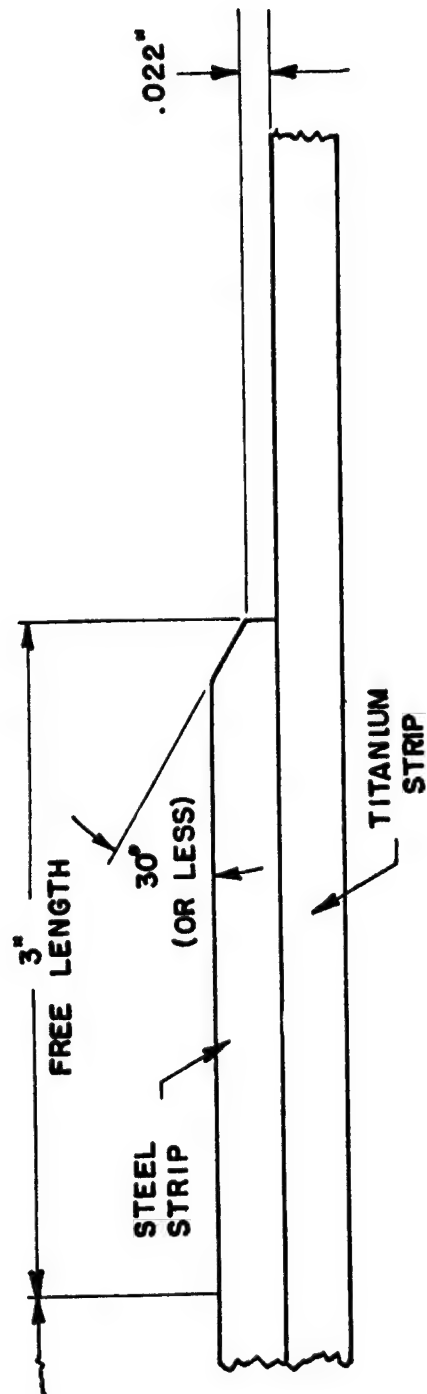


Figure 43
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LINER FILM TEST



(NOT TO SCALE)

Figure 44
71

LOW TEMPERATURE TENSILE PROPERTIES
OF
B120VCA Ti - AGED AT 900°F - 75 HRS.
AC (HEAT #F-6236 - GAGE - 0.090")

<u>Test Temperature</u>	<u>Condition</u>	<u>UTS</u>	<u>Elong- ation in 1" (%)</u>	<u>RA (%)</u>	<u>RATIO: Notched UTS Smooth UTS</u>
Room Temperature	Smooth	214.0	3.4	4.9	0.78
	Notched	164.1	1.0		
-35°F	Smooth	220.6	1.5	3.1	0.61
	Notched	135.5	.3	0.5	
-65°F	Smooth	227.2	1.2	1.5	0.57
	Notched	129.5	.05	0.1	
-110°F	Smooth	235.8	1.0	0.5	0.52
	Notched	121.5	0	0	
-320°F	Smooth	190.0	0	0	0.34
	Notched	64.0			

FIG. 45

LOW TEMPERATURE TENSILE PROPERTIES OF BI20 VCA TITANIUM

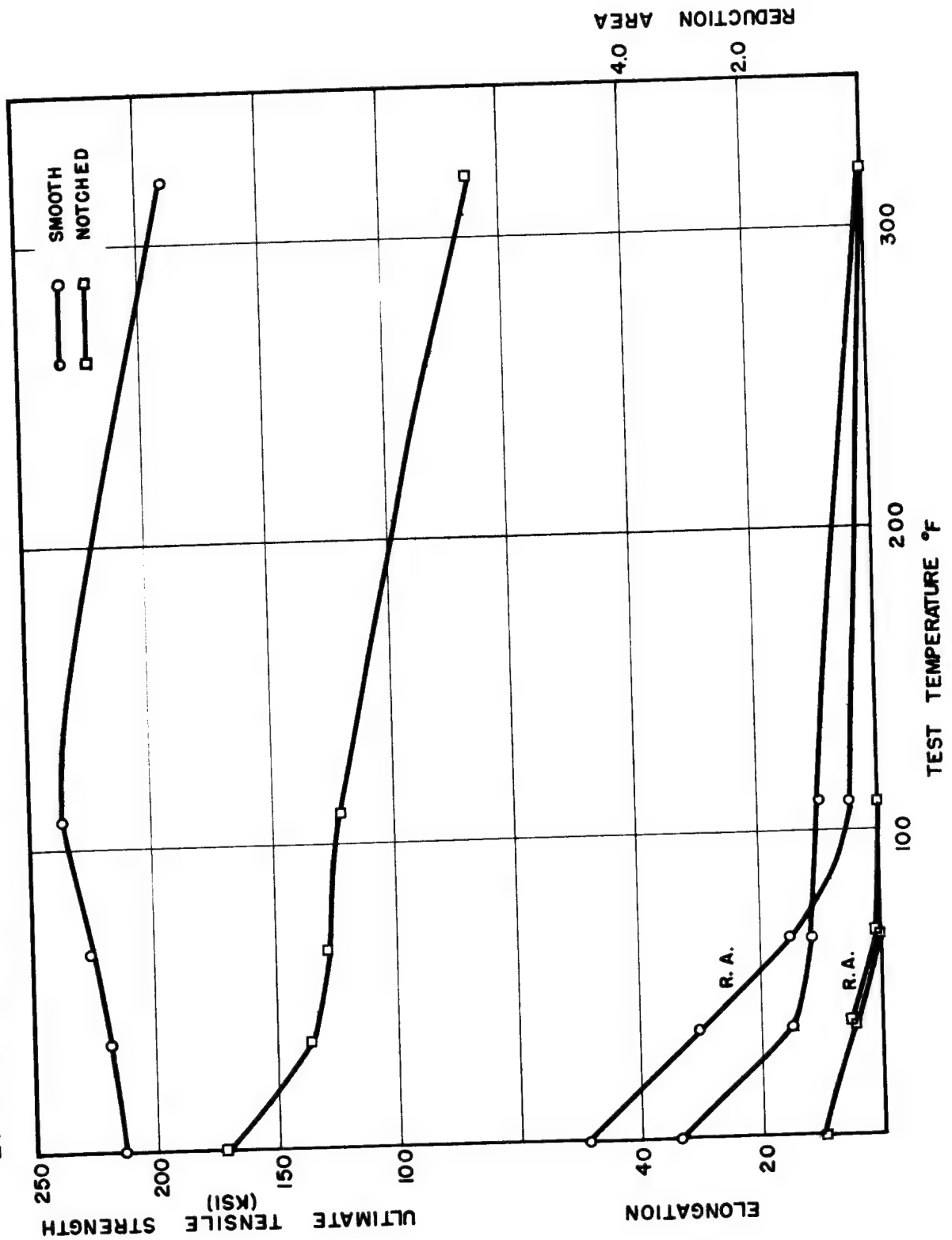


Figure 46
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6.0 EXPERIMENTAL MANUFACTURING

6.0 EXPERIMENTAL MANUFACTURING

The manufacture of two 6.2" I.D. sub-scale vessels, employing the tape configurations illustrated in Figures 3 and 4, was accomplished on a converted lathe shown in Figures 47 and 48. This piece of equipment consists of the following components:

- (a) Wrapping Apparatus (6T-60924)
- (b) End Adapters (LS-25439-7)
- (c) Collapsible Mandrel (6T-60925)
- (d) Reel Equipment (6T-60988)
- (e) Dummy Arbor (DA-32360)

6.1 Wrapping Apparatus

The wrapping apparatus (Figure 49) rolls over the mandrel assembly (described in the following section) on the ways of the lathe. It is initially supported on three legs. The apparatus is fitted with three equally spaced and free rotating rollers. Two of the rollers are mounted on shafts which are clamped to the frame and the third is mounted on a cylinder. This system is capable of applying a rolling radial force of 2500 pounds on the tape. By application of the rolling force, the apparatus lifts from its legs and centers itself on the mandrel. The roller shafts are axially and angularly adjustable by means of gage blocks and sine bar devices mounted at the shaft ends (Figure 49). This provides a means of tilting the rollers to the wrapping helix angle while maintaining their correct axial positions. A spring loaded guide pushes the tape axially at the point of tangency as the tape is fed on the mandrel. Three sets of rollers are required to wrap a vessel. Each set of rollers is formed to suit the particular tape shape. The apparatus is attached to the compound of the lathe carriage through tie rods for driving through the lathe lead screw. This provides axial and square adjustment of the apparatus while it is engaged in the lead screw pitch. By removing the tie rods, the apparatus may free-track to follow the pitch of a tape lay.

Trail wrapping was attempted with spring loaded tie rods pulling the head in the anti-wrapping direction with forces which are great enough to overcome the friction between the tape and the arbor. The tests were unsuccessful since the

6.1 Wrapping Apparatus (Continued)

rollers pulled out of the tape track. The rollers were subsequently reworked to remove the .010" radii at their edges. Another trial run showed them to still roll out of the tape track. It was then concluded that the head must be able to track freely, uninhibited by external forces.

The tie rods were removed and the same tape was wrapped with the head tracking freely. The roller helix angle or tilt was set for .190" pitch or .010" less than the channel width. As the channel winds on the arbor, it is continuously pushed at the shoulder by the difference in pitch, which causes the tape to slip on the arbor until it butts the previous wrap (Figure 50). After butting is achieved, the roller slips on the tape to make up for the pitch difference. This is a continuous and smooth occurrence since the displacements are achieved in the circumferential length of 20 inches in each turn. The first trial of 14 wraps measured .011" more than 14 times the mean width of the channel. A second trial with a more uniform channel was wrapped 17 turns with a measured length of .0005" more than 17 times the mean tape width. This method of wrapping is considered acceptable for the first layer.

Trial wrapping of the second layer was first attempted with an embrittled tape section which failed under load. A second attempt was made using a unheat-treated length which distorted under a load of 1500 pounds and required 500 pounds to bottom on the first layer. The second layer was wrapped successfully with a 1000 pound radial load, but the interference fit was not sufficient for full interlock.

The third layer was similarly wrapped with a 1000 pound radial load. The three layers shown in Figure 51 were wrapped on the dummy arbor demonstrating that the wrapping technique, except for increased interference fit, is feasible.

6.2 End Adapters

300M and SAE 52100 steel end adapters are rough turned, heat treated, and ground all over. All helical surfaces are ground on a thread grinder in the solid stock. The grinding of the inner tape is done after assembly in order to maintain adapter strength during wrapping and mandrel stripping. The technique developed for grinding the helical surfaces utilizes a set of wheel dressing cams which provides a "V" shaped wheel edge with a 24° included angle. The point is dressed down so that

6.2 End Adapters (Continued)

the wheel grinds a groove of .0544"-.0536" width when fed to a sufficient depth. The adapter is clamped on an arbor (Figure 52) which has angular scribe marks to permit rotation and re-indexing of the adapter relative to the wheel and arbor which are constantly engaged in the machine's .200 pitch. In this manner, control of the pitch is maintained while the same wheel is relatively shifted from position to grind the other groove shapes which are off the pitch lines.

A comparator chart of 62-1/2 magnification was used to check the helical surfaces on an optical comparator.

The grinding of the inner taper is done after assembly in order to maintain adapter strength during wrapping and mandrel stripping. A support tube (Figure 53) was designed and fabricated which clamps the adapters of a finished vessel. This tube supports the vessel during grinding of the tapers and also acts as a protective case for the vessel.

6.3 Collapsible Mandrel

The end adapters are assembled and clamped on a mandrel (Figure 54) which holds them in position and provides a core for wrapping. This mandrel is capable of absorbing the wrapping loads and is collapsible and retractable after wrapping. It consists of a solid stepped shaft (Figure 55) onto which a five-segment shell is assembled. The segments were made from two hardened cylinders which were ground on the I.D. to fit the center shaft and on the O.D. at each end to fit the counter-bore in the locating rings. The segments are clamped to the shaft by means of the locating rings which are piloted on the shaft and are in turn clamped in the assembly. The end adapters are assembled on the locating rings and held axially between the segment's shoulders and end plates. The adapters are free to rotate for angular positioning by adjustment of the end plates. In disassembly, the end plates are removed and one locating ring removed by pull-out screws. The assembly is located on a sleeve which permits the pressing out of the shaft which in turn pushes out the second locating ring. The pressing load is opposed by the reaction load passing through the sleeve, the end adapter, and the segments. The segments are then free to be pulled to the center and withdrawn. During wrapping, the mandrel assembly is driven on a lathe between the face plate and a live center (Figure 56).

6.3 Collapsible Mandrel (Continued)

The extraction of the mandrel, after wrapping, required approximately a 10,000 pound force. This was resulted in the dragging of the tape causing a "saw-tooth" effect. In view of this, a new inner core was designed and constructed for the collapsible mandrel. The new core incorporates a 1/16 inch thick "Cero Alloy" sleeve which will be melted before extraction of the core, and thus reduce the extraction force.

6.4 Reel Equipment

Reel equipment is mounted on the lathe head and locates the tape reels in the axial location of the mandrel. Each reel (Figure 56) holds enough tape for one layer and spaces it to the wrapping pitch. The reel is mounted on a shaft which is supported between bearings (Figure 57). A drag brake is mounted at one end of the shaft and is controlled by a potentiometer which can vary the tape tension in a range of 0-400 pounds.

6.5 Dummy Arbor

A dummy arbor (Figure 58) which simulates a mandrel assembly with end adapters has been designed and fabricated. This is a hardened, solid steel arbor which is used in the development of wrapping procedures. Variables due to tape tolerances and assembly of parts are minimized so that the adapters and mandrel are not jeopardized during development.

6.6 Staking

This method of joining the tapes to the adapters includes drilling for pins in the hardened tape and adapter material on a sensitive drill. The drilling must be done at the wrapping machine with a hand drill which presents risk of drill breakage. The drilling of the end adapters requires solid carbide drills which are extremely brittle. The staking pin size has been increased to 1/16" to reduce drill breakage.

6.7 Wrapping Development

Trial wrappings of the first layer were made with the roller helix angles set for .200" pitch and the wrapping head driven by the lathe lead screw. The resulting spacing was erratic. The first layer must be wrapped with channels butting tightly to permit fitting of the second layer interlock. Several modifications were made to the wrapping apparatus primarily for this

6.7 Wrapping Development (Continued)

purpose. The probability of tape width, the head tracking rate, and the lathe lead being exactly the same is remote. Therefore, axial slippage is expected and should be used to advantage. Fixing of the head to the lathe lead screw, as originally contemplated, is not considered practical.

Experiments were then run with the wrapping apparatus on the bare dummy arbor using various roller helix angles and radial loads. An inconsistency in the tracking rate was detected. Eccentricities in the roller shaft assemblies and deflections in the apparatus due to machining tolerances and roller loads were noted. Corrected base line settings on the shaft assemblies were established to minimize the effect of these deviations.

Experiments were also carried out to determine the axial drag force required to overcome the clamping load of the rollers on the bare arbor. The apparatus was set to track the arbor by means of roller tilt and clamping load. Cables, fitted with a spring balance, were attached to the frame and fixed at opposite ends. The apparatus tracked the mandrel until the restraining force of the cables caused slippage between the rollers and the arbor. Coefficients of friction between .120-.126 were realized. A similar test was run with short pieces of channel tape located between the rollers and the arbor, but without rotation of the arbor. The drag force indicated a coefficient of friction of .5, approximately.

A modification was made on the wrapping apparatus which incorporated a third tie rod between the wrapping head and the lathe compound (Figure 59). The three equally spaced rods were fitted with springs and preloaded to pull the head back from the wrapping direction, thereby stacking the first channel tightly with a predetermined load.

In previous trial wraps, the radial forces used were 500, 1000, and 1000 pounds for the first, second, and third layers, respectively. The tape tension remained at 200 pounds.

No problems were encountered during the dummy arbor wrapping of the first layer. The second layer ("I" beam), however, fractured under the 2500 pound load on the first few laps over that portion of the cylinder equivalent to the adapter piece. The load was reduced to 1000 pounds over the adapter portion and then increased to 2500 pounds over the titanium-to-titanium interlocking sections without further cracking. The third layer was wrapped using a 500 pound load on the steel and 2500 pounds on the titanium without difficulties.

6.8 Wrapping Vessel No. 1

Vessel No. 1 (Figures 60 and 61) was wrapped, staked, and the mandrel successfully withdrawn. The force necessary to withdraw this mandrel was 10,000 pounds. This vessel appeared to be rigid and able to withstand handling despite the following condition:

- (a) A variation in outside diameters between the end adapters and the mandrel resulting in an adapter to mandrel step. Wrapping difficulties occurred in these zones on all three layers. It is felt that this situation caused a "saw-tooth" effect on the inside of the vessel when the mandrel was extracted.
- (b) The tape used (both "I" beam and channel) was slightly out of tolerance.
- (c) An incorrect "as-received" helix on the third layer increased the tendency of this tape to eject the staking pins. This incorrect helix also caused the tape to form an "S" shaped curve coming off the wrapping reel. This condition produces difficulty in attaining a tight loop-to-loop (side face) contact. It was learned from these problems that the third layer (channel) must be wrapped during the tape manufacture process onto the drum with the legs facing inward.

Wrapping of the first layer employed the proper shaped rollers loaded to 500 pounds radially with a tensile force on the tape of 200 pounds. These rollers were free-tracking and were set at a retarding pitch of 0.190 inch; the wrapping pitch being 0.200 inch. The proper angular alignment (about its axis) of the terminal end-adapter was accomplished using a "Jo" block of a thickness equivalent to a multiple of the actual channel tape width. A gain of .001 inch in width for each turn due to the compressive deformation of the tape was measured resulting in a cumulative total terminal loss of .043 inch for the complete first layer. No measurable space between turns was observed. An "Indiac" concentricity measuring device showed maximum runout of 0.002 inch except in the adapter-to-mandrel transition areas where the step caused the instrument to run off scale.

The second layer, rolled with wide, plain rollers, cracked under the imposition of the high (2500 pounds) radial force.

6.8 Wrapping Vessel No. 1 (Continued)

A check of the end adapters revealed that the adapter section which fits into the groove of the "I" beam was wider than the tape groove and that sharp edges existed. By breaking these edges, the interference fit was reduced and cracking eliminated. This second layer was removed and, using new tape (having the same cross-section), rewound under a radial force of 1350 pounds.

The third layer (channel) also was confronted with the "step" problem. In addition, the application of the high radial rolling force (2500 pounds) plastically deformed the tape thus increasing the basic width of the channel by .0014 inch. The first few loops were unwound and the tape width reduced to 0.200 inch by hand filing. Pressure tests on subsequent wraps indicated that a gage setting of 45 psi (1300 pounds approximately), applied radially, was the optimum non-deforming force permissible. This setting was used to complete the wrapping of the third layer.

6.9 Wrapping Vessel No. 2

The first layer was successfully wrapped with a radial load of 570 pounds and tensile load of approximately 80 pounds.

The second layer bottomed and locked with a radial load of 870 pounds and a tensile load of 80 pounds. A radial load of 1000 pounds caused distortion. Towards the end of the second layer at the terminal point of the first layer, a space developed between the first layer and the end-adapter shoulder. The staking pin for the first layer was removed, the adapter was rotated to close the space and wrapping of the second layer was completed. The space could be caused by a .0002 compression of the channel tape in the interference fit. The tape used in this vessel was not heat treated.

The third layer required a 1200 pound radial load and a 180 pound tensile load. No difficulties were encountered until the channel reached the first groove on the end adapter, at which point it was displaced approximately .005 forward. The last wrap had to be filed to fit.

After completion of wrapping and staking, the collapsible arbor was removed on an arbor press with no difficulty. The arbor extraction force was estimated at 5 tons. The inner tapers on the end adapters were machined to finish the vessel.

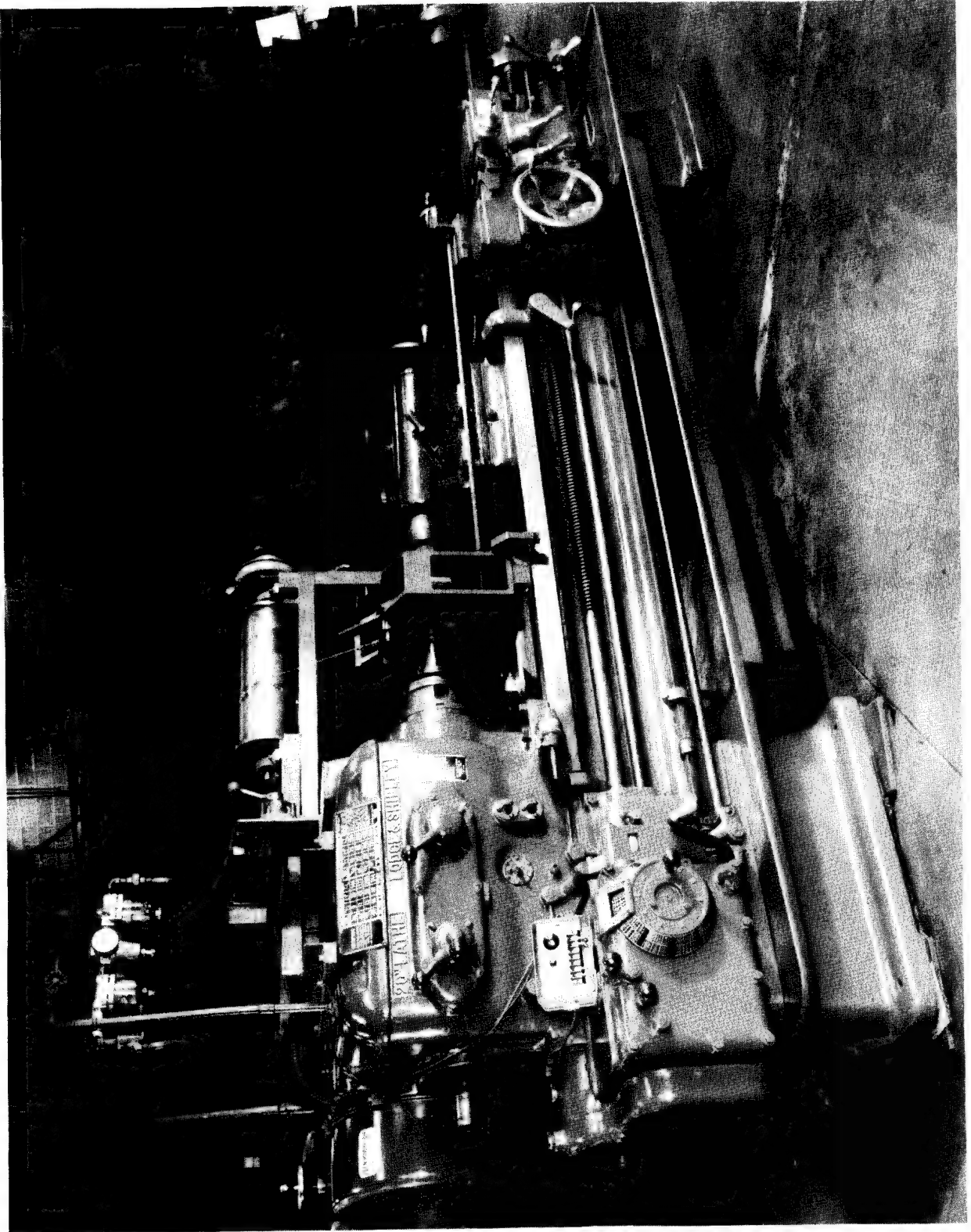
6.9 Wrapping Vessel No. 2 (Continued)

The finished vessel was approximately .020" smaller in diameter at the center than at the ends with .004" total runout of the end faces. The outer diameter remained smooth but the inner bore was slightly stepped in a manner resembling rifling. This indicates that the interlock between the 1st and 2nd layer is incomplete.

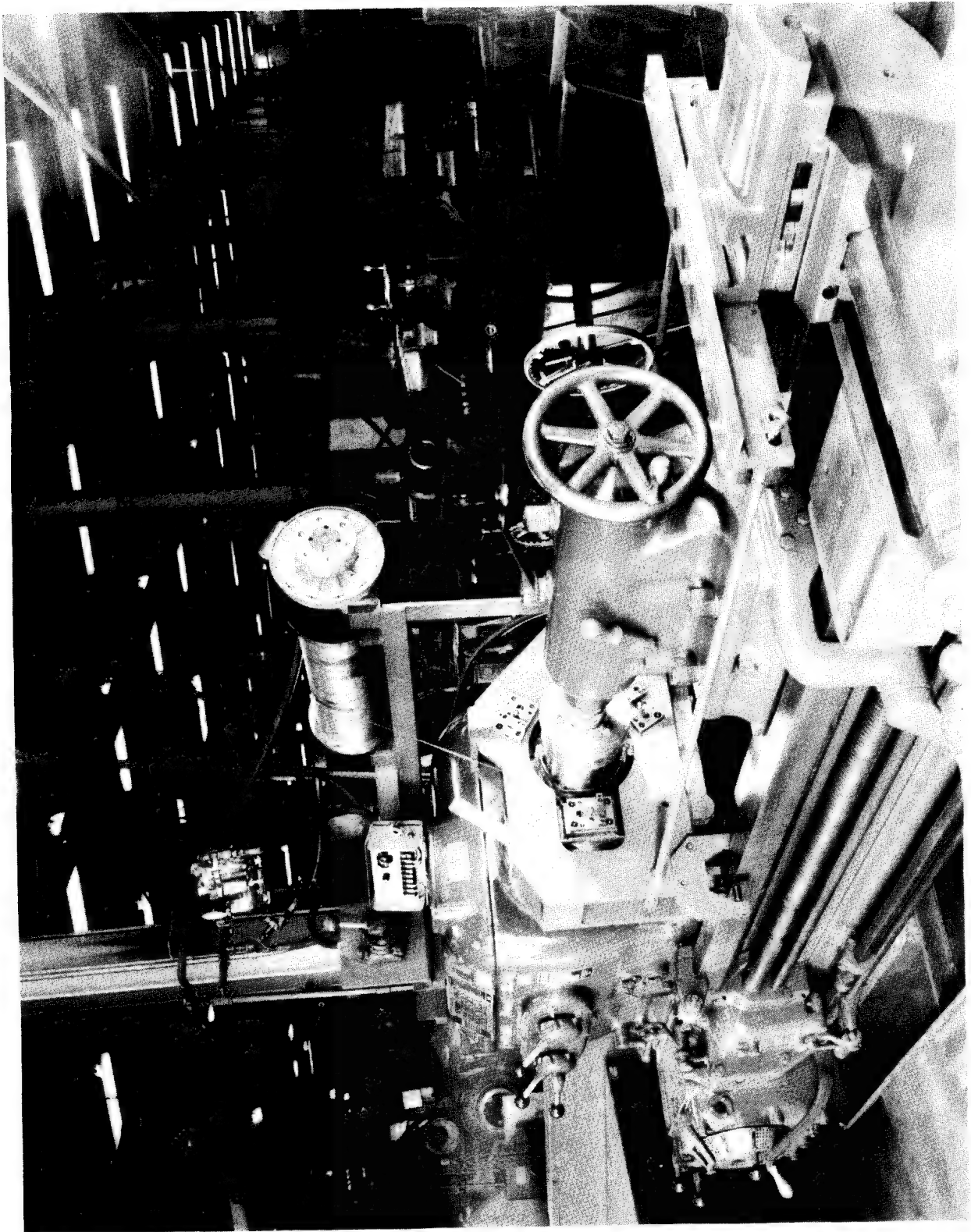
Generally, the wrapping was indicative of the feasibility of the technique. Better results are expected with more accurately sized tape with the required strength and ductility.

This vessel pressurized and leaked at 30 psig. The leak was caused by a separation of the tapes at one end of the vessel. Since the separation occurred near the edge of the end adapter, it was surmised that the flaw was caused by a compression of the end adapter as the mandrel parts were being withdrawn. The tensile force on the tape during wrapping imposes a hoop stress which is transmitted to the end adapters and the mandrel as a radial compressive force. As each portion of the mandrel is removed, the vessel contracts in that area. The first portion removed is located under the adapter near the point of failure. However, a good interlock between the tape layers should hold the vessel intact until the remainder of the mandrel is withdrawn. A modification on the mandrel could be made to permit a collapse prior to withdrawal.

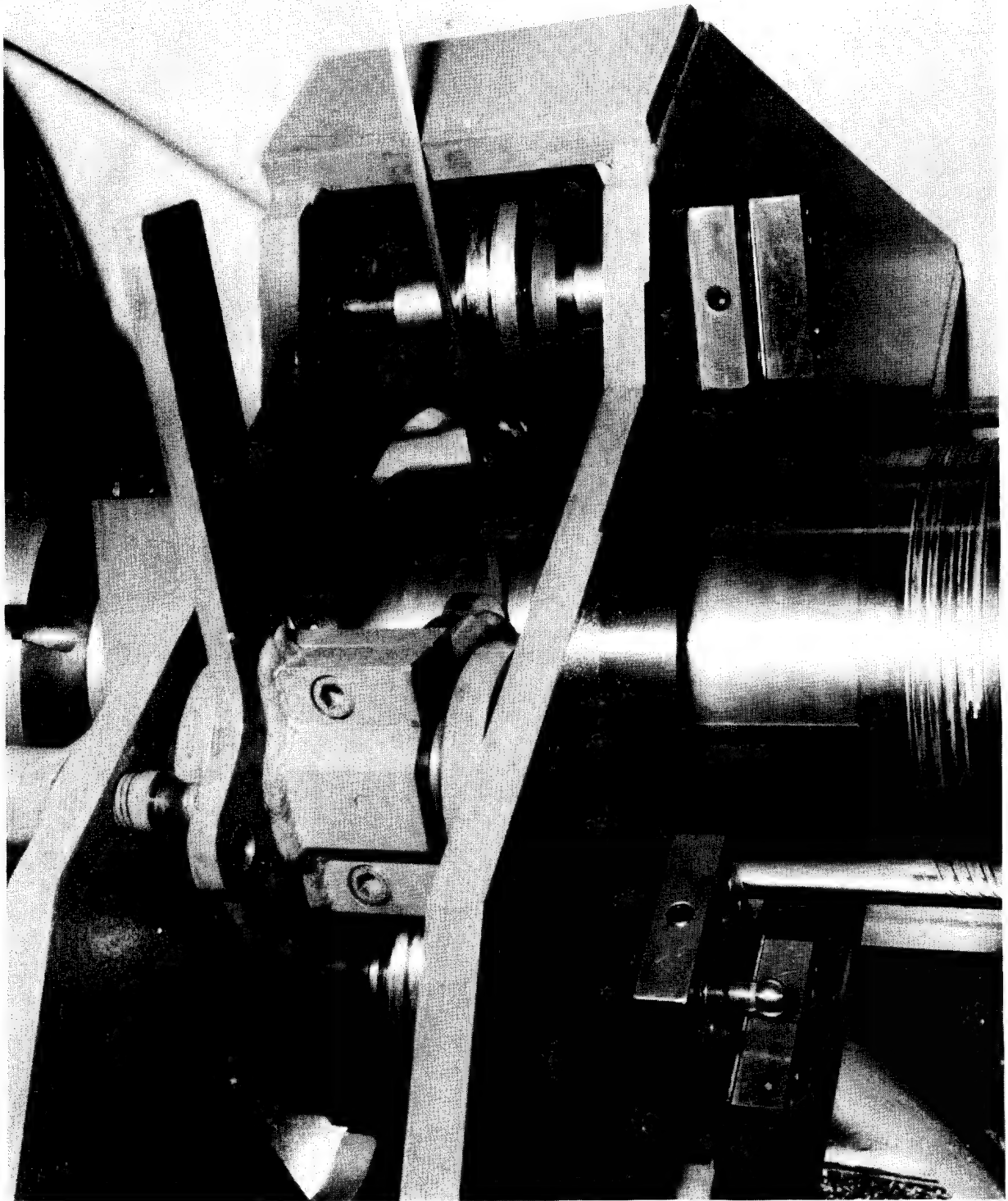
This separation was plugged by casting an inner and outer shell of a low melting alloy. A second test was conducted which resulted in failure at 50 psig. The vessel separated in the center section far from the end adapters. The tape layers unwound easily indicating a lack of interlock. These sectional radii and the locking angles were enlarged and the "I" beam was found to be twisted. It appears that after wrapping when the mandrel was withdrawn, the wrapping stresses were relieved by contraction of the vessel. The "I" beam twisted toward its free position (Figure 62) and a stagger "tooth effect" developed on both the O.D. and the I.D. of the vessel. It is suspected that the tape layers were not bottomed and the interlock was insufficient to prevent twisting.



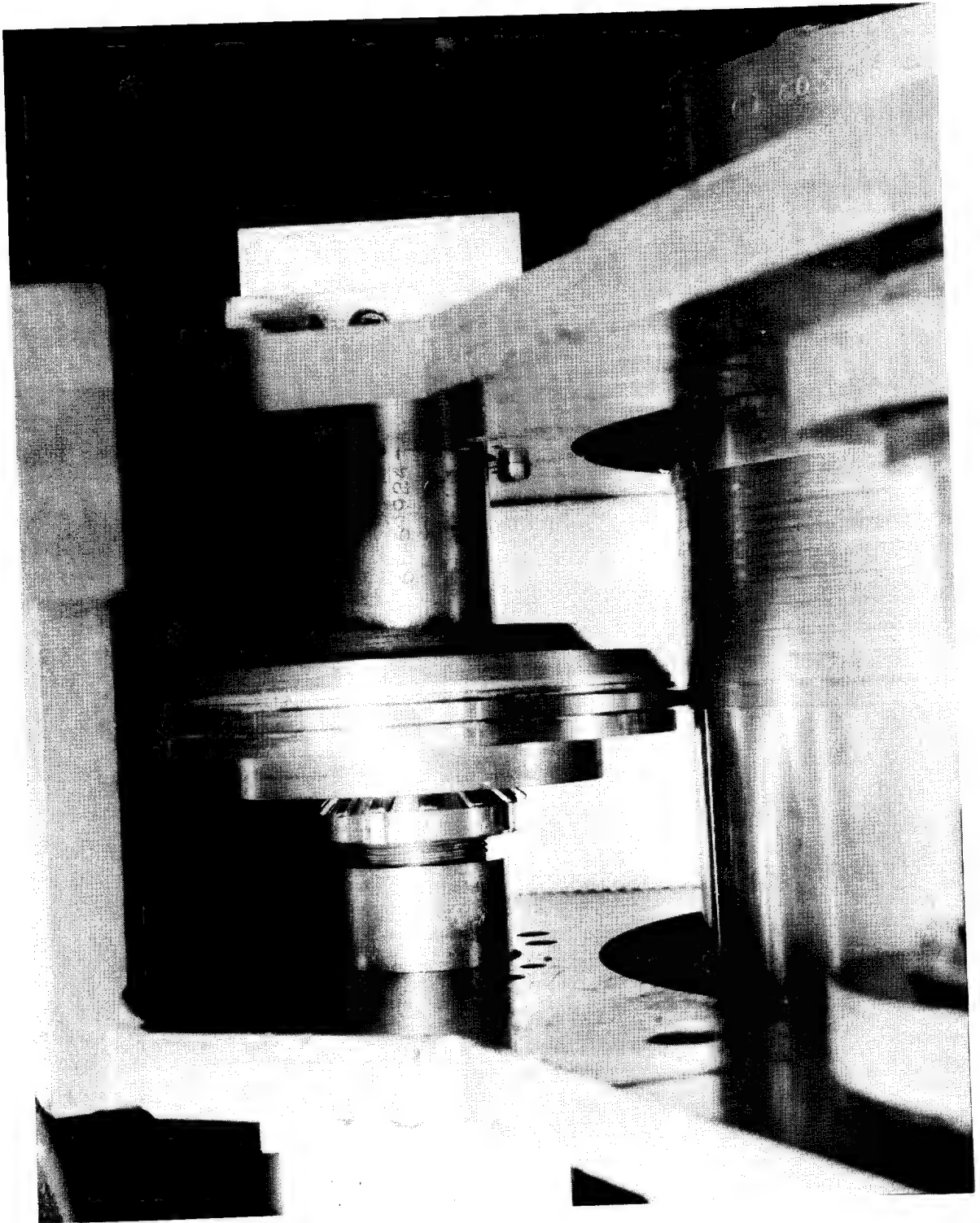
Tape Wrap Machine



Wrapping Apparatus Close-Up



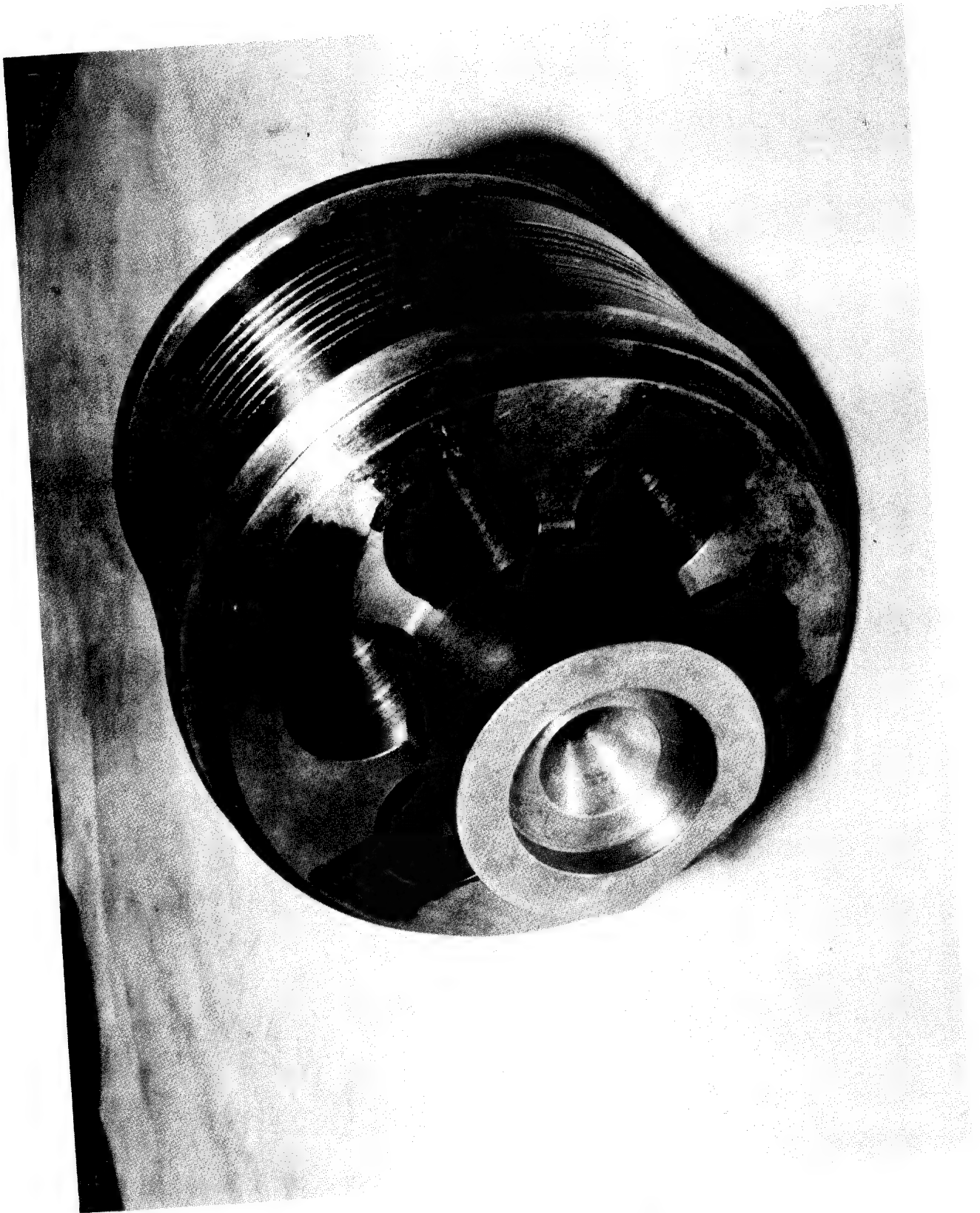
Wrapping Apparatus



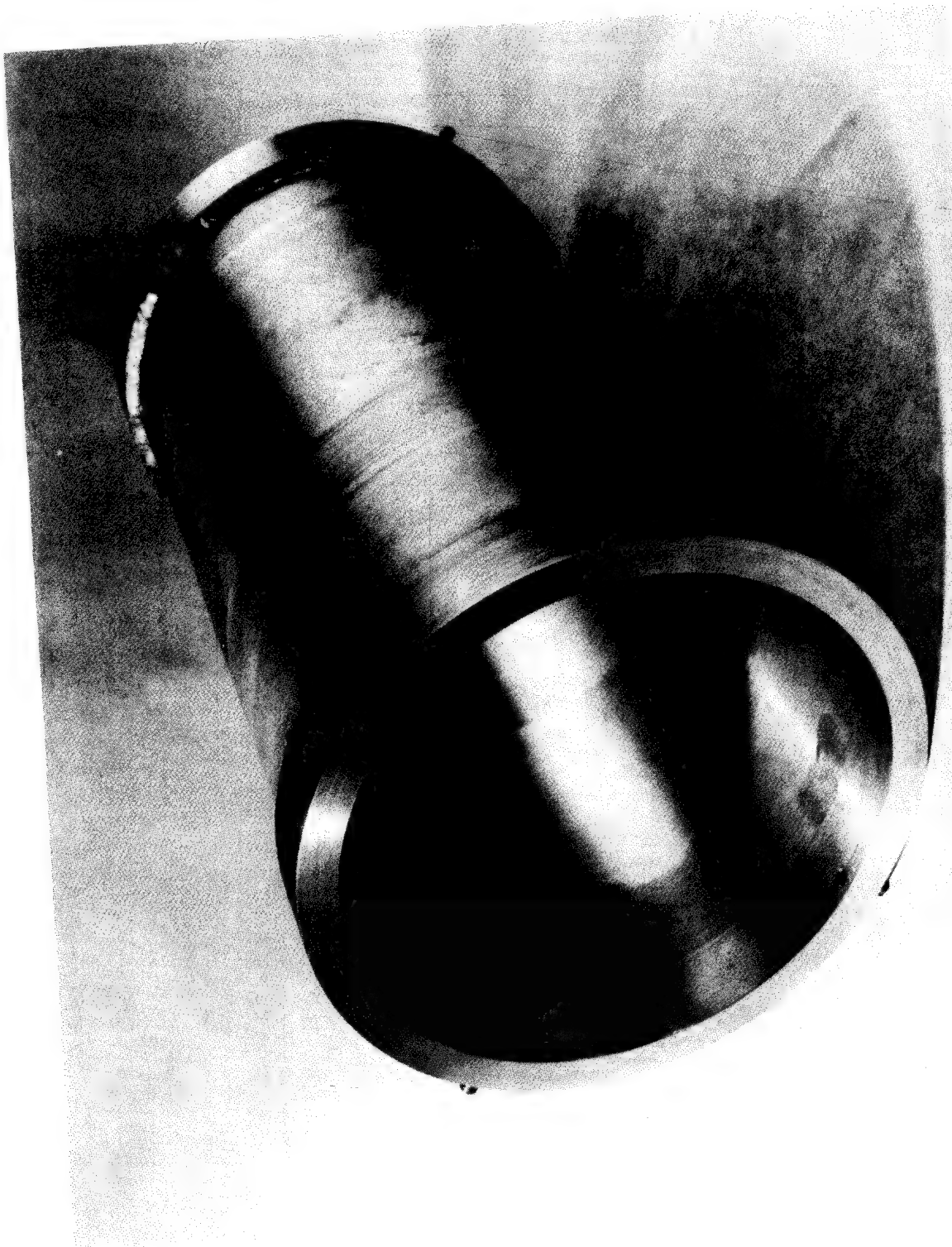
Close Up of Roller on Channel Wire



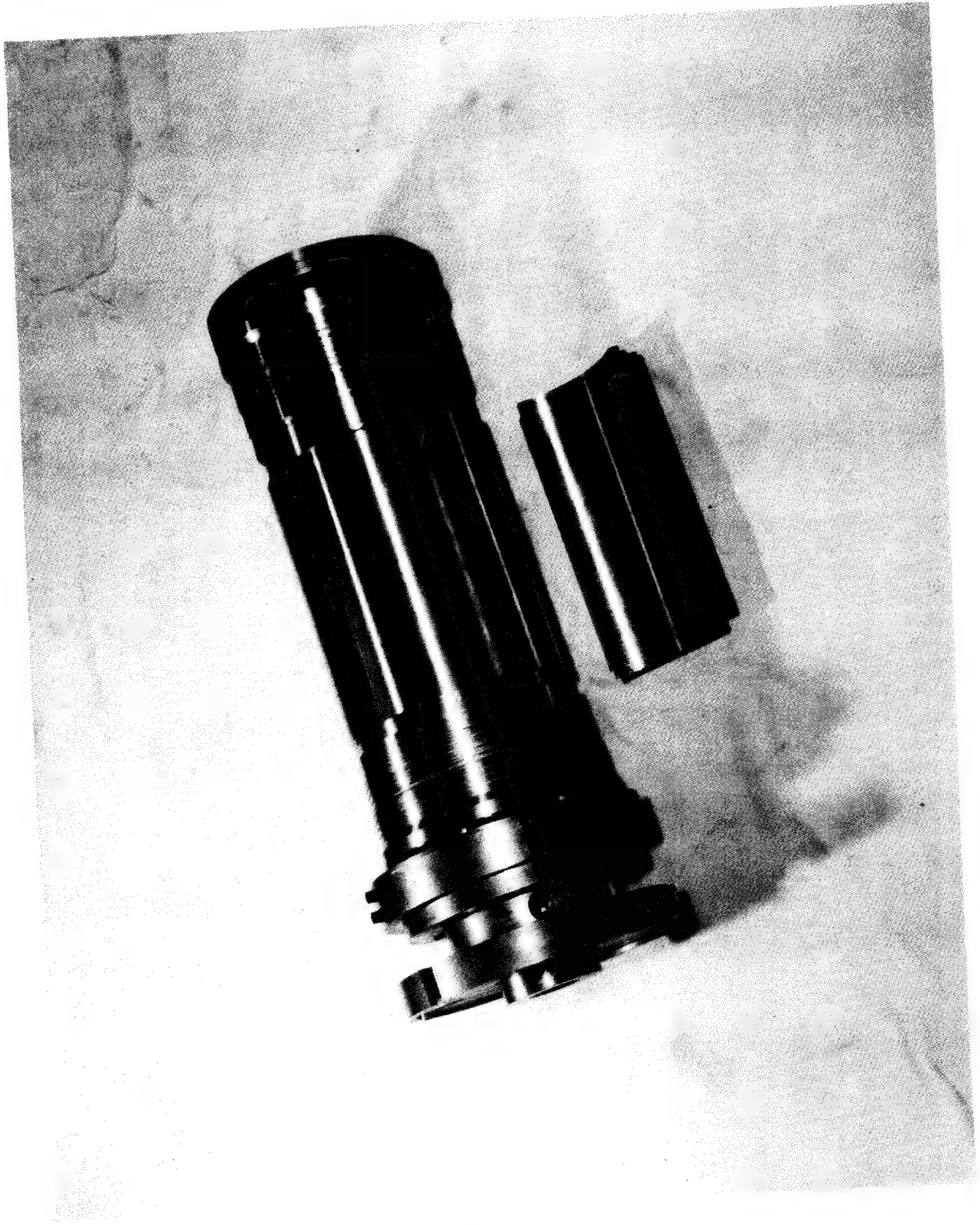
Three Layers Wrapped on Dummy Arbor



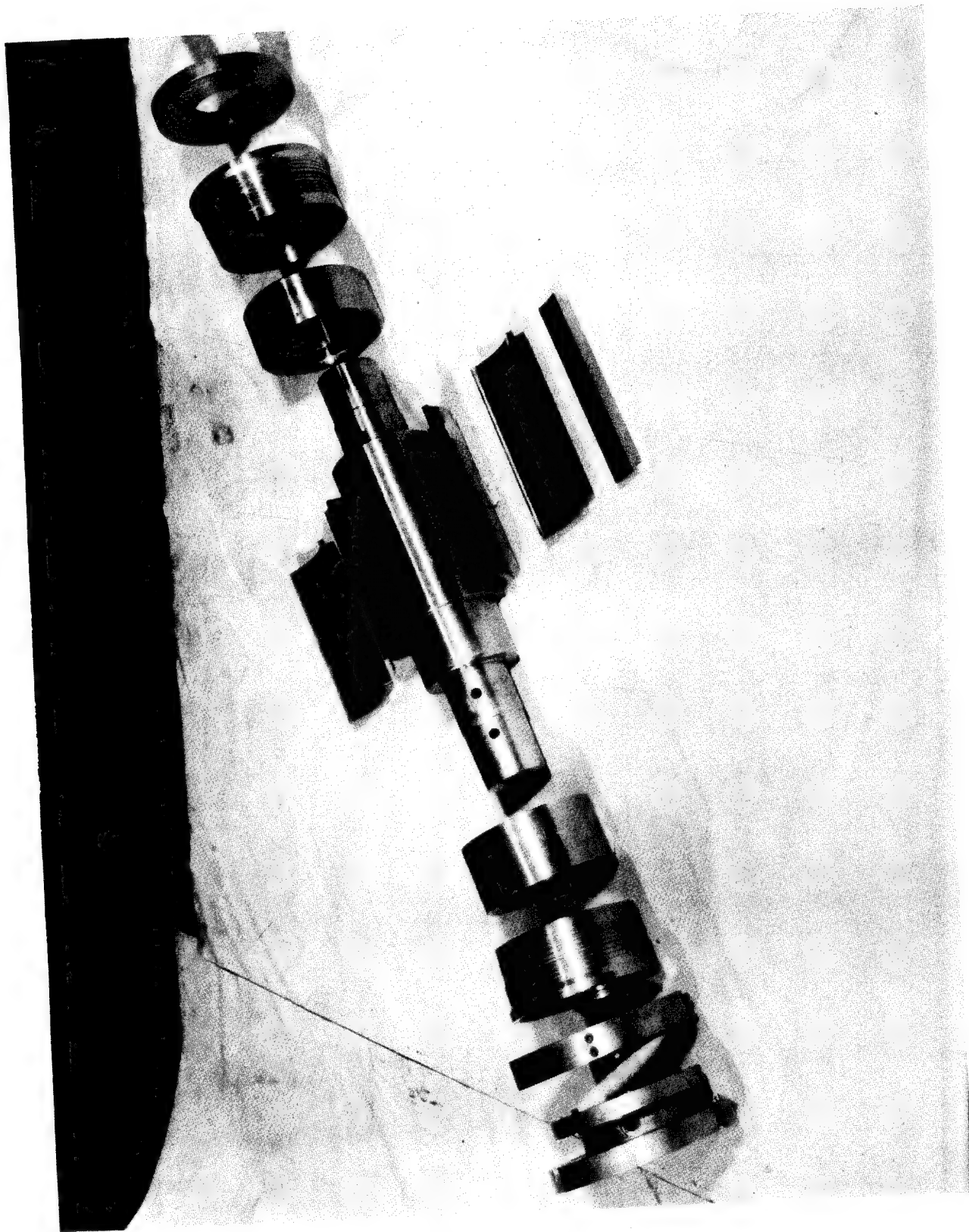
Adapter Clamped to Arbor



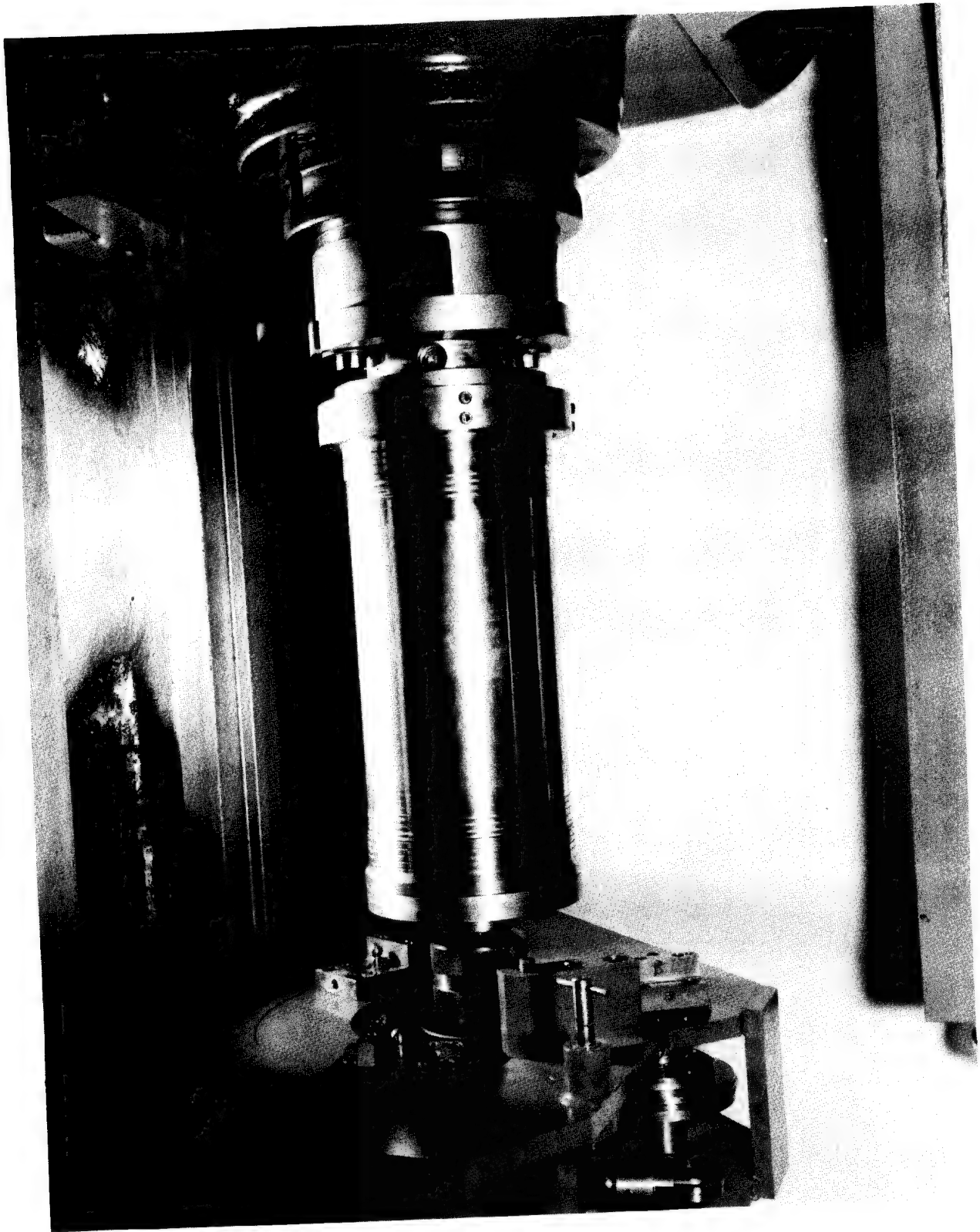
Support Tube



Mandrel Assembled



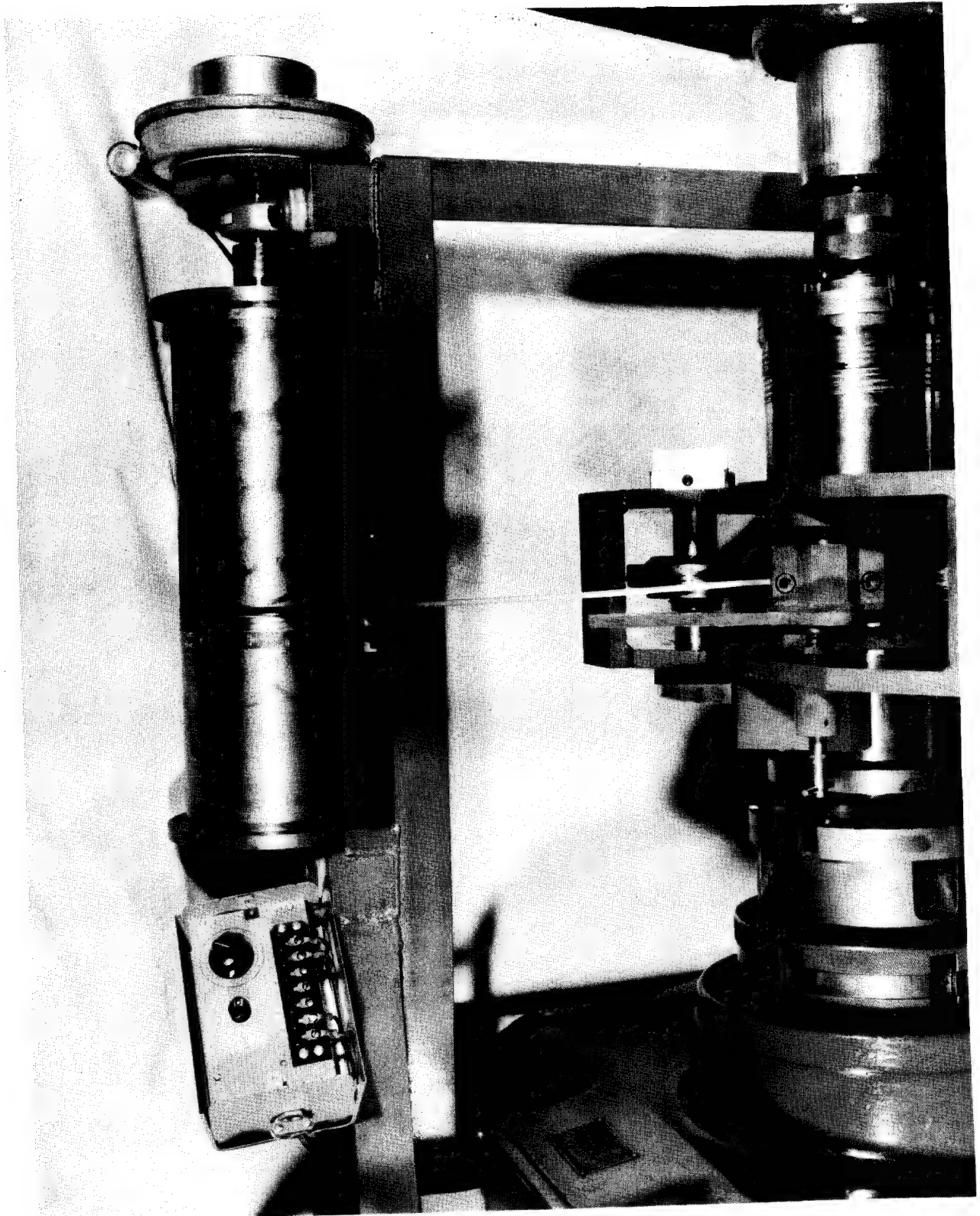
Exploded View of Mandrel



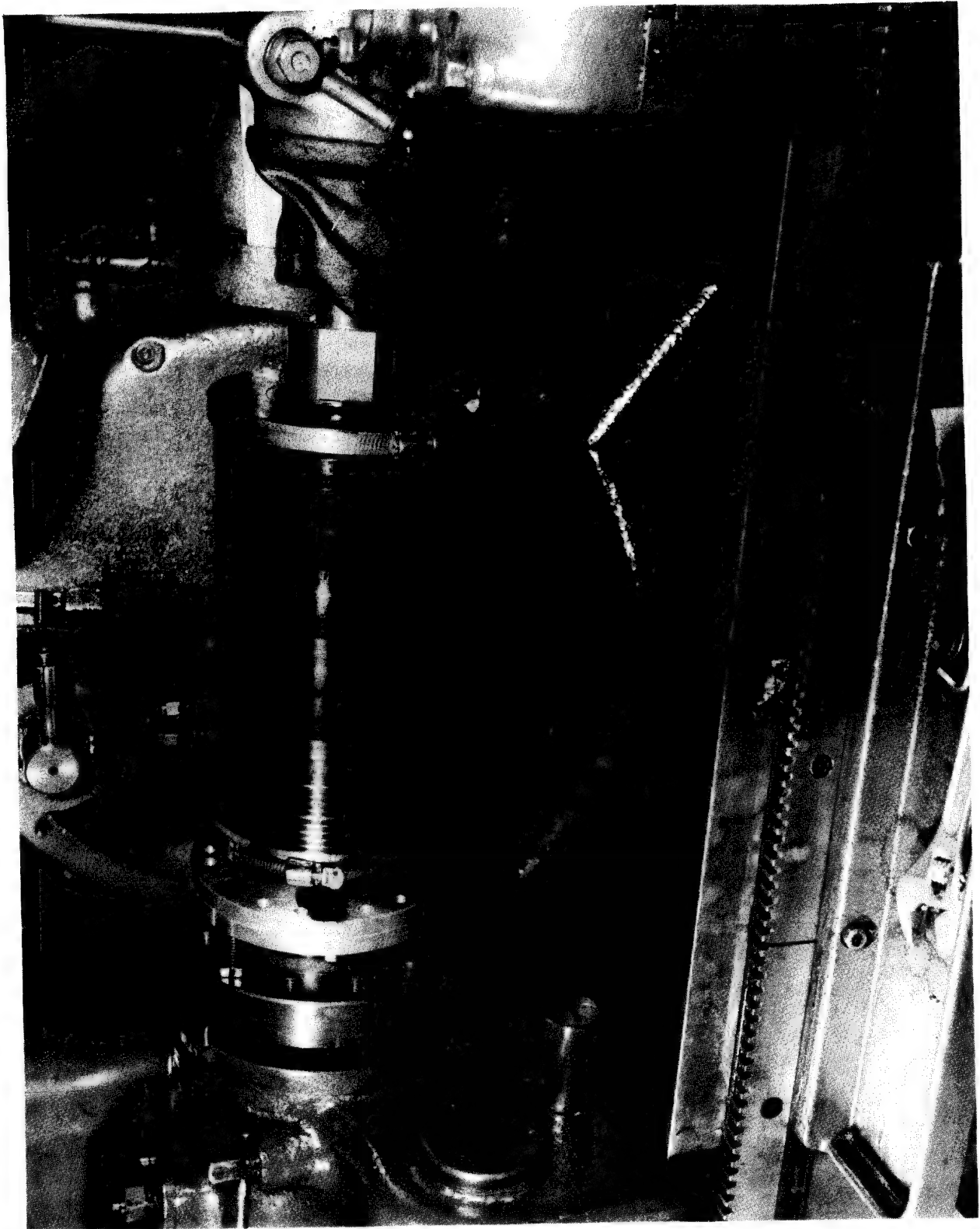
Mandrel Set on Lathe



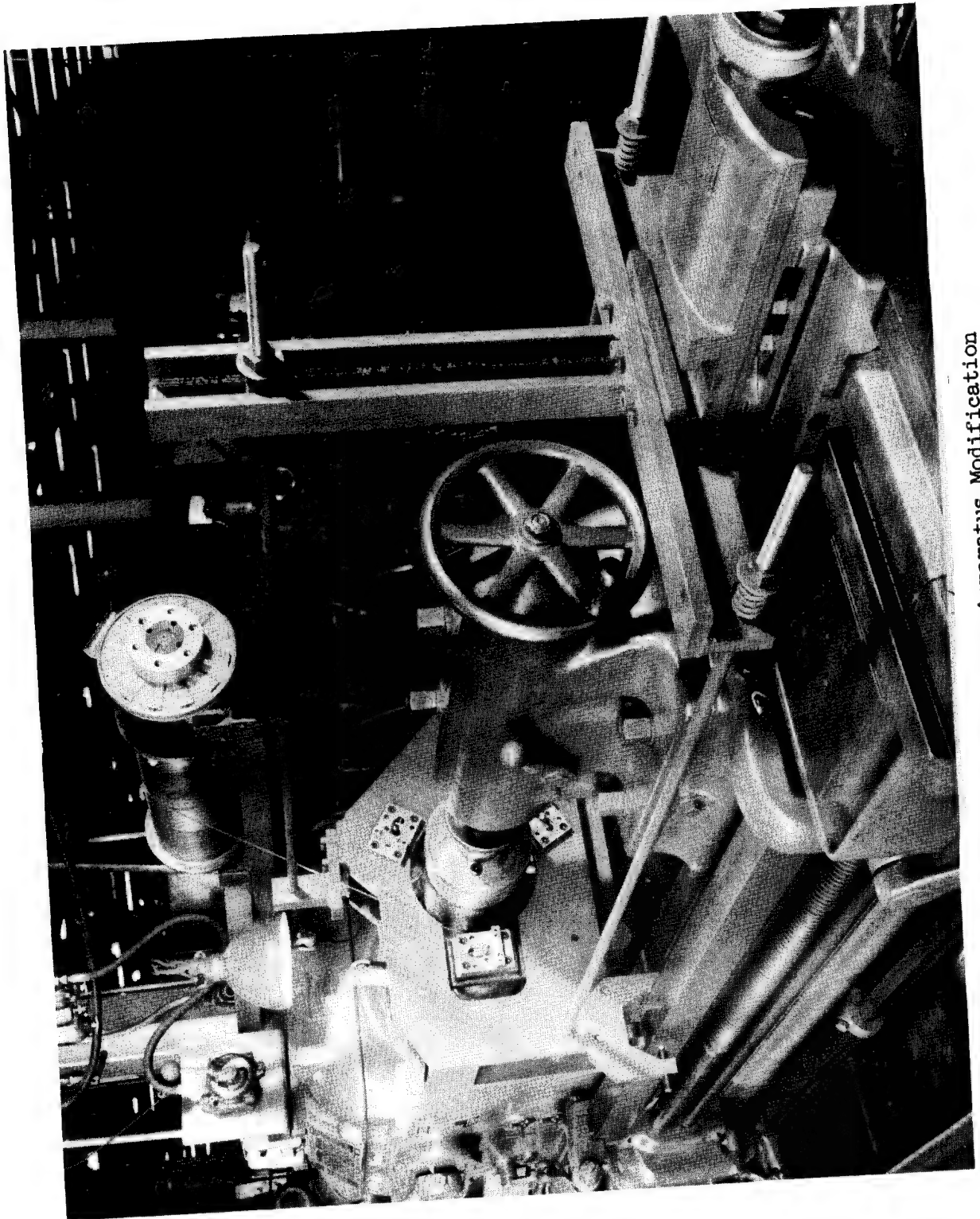
Reels



Drag Brake



Dummy Arbor



Wrapping Apparatus Modification

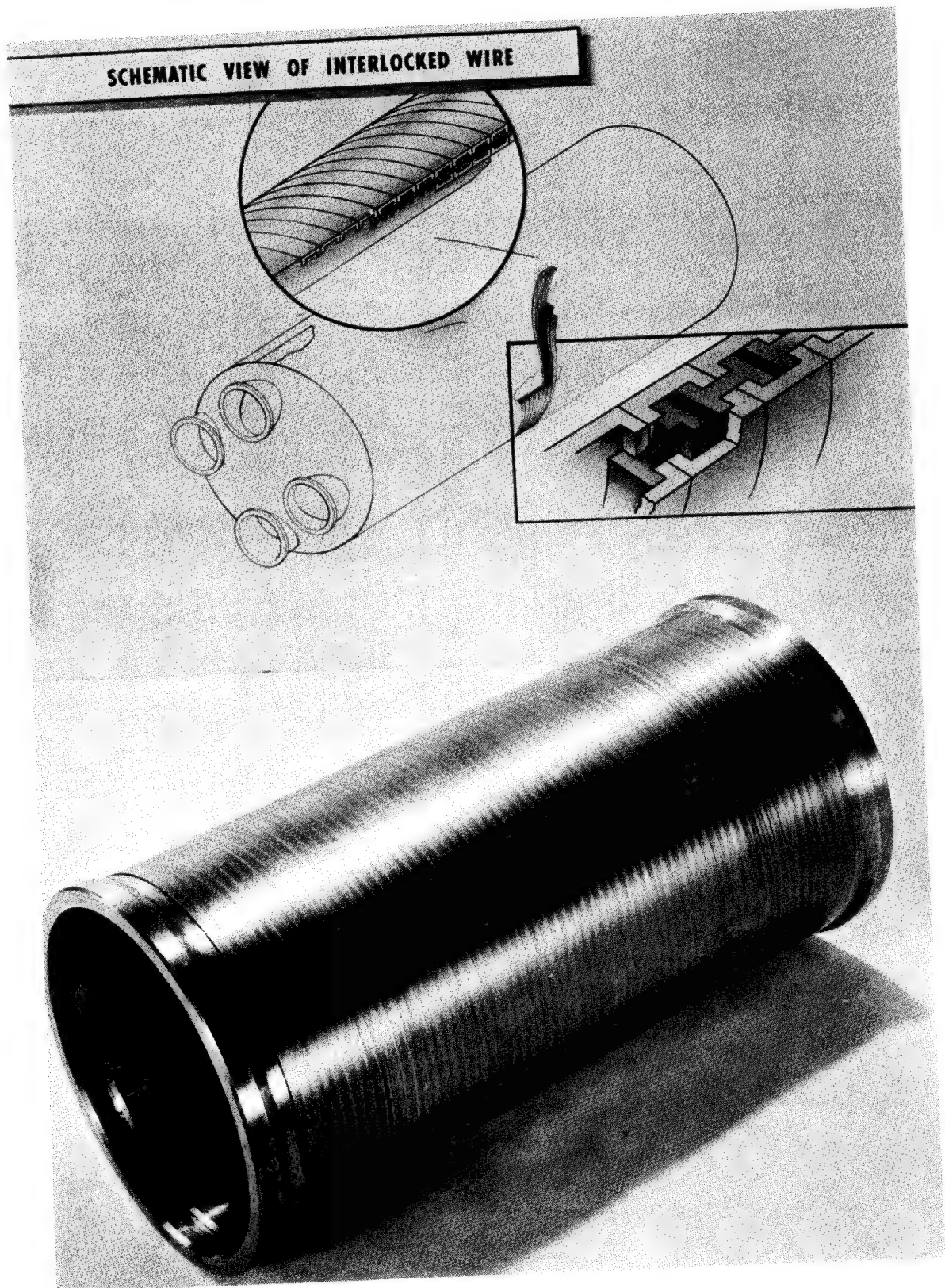
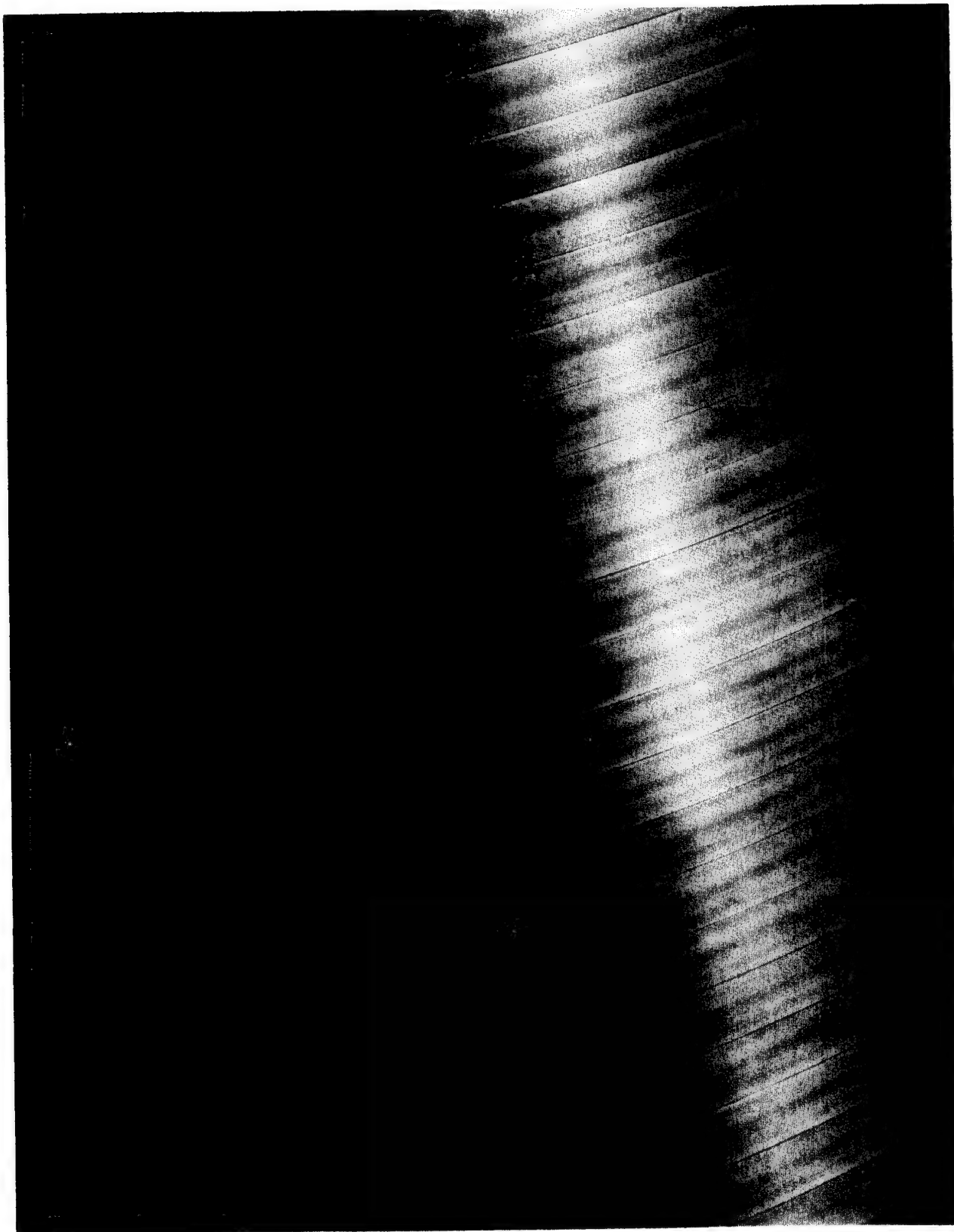
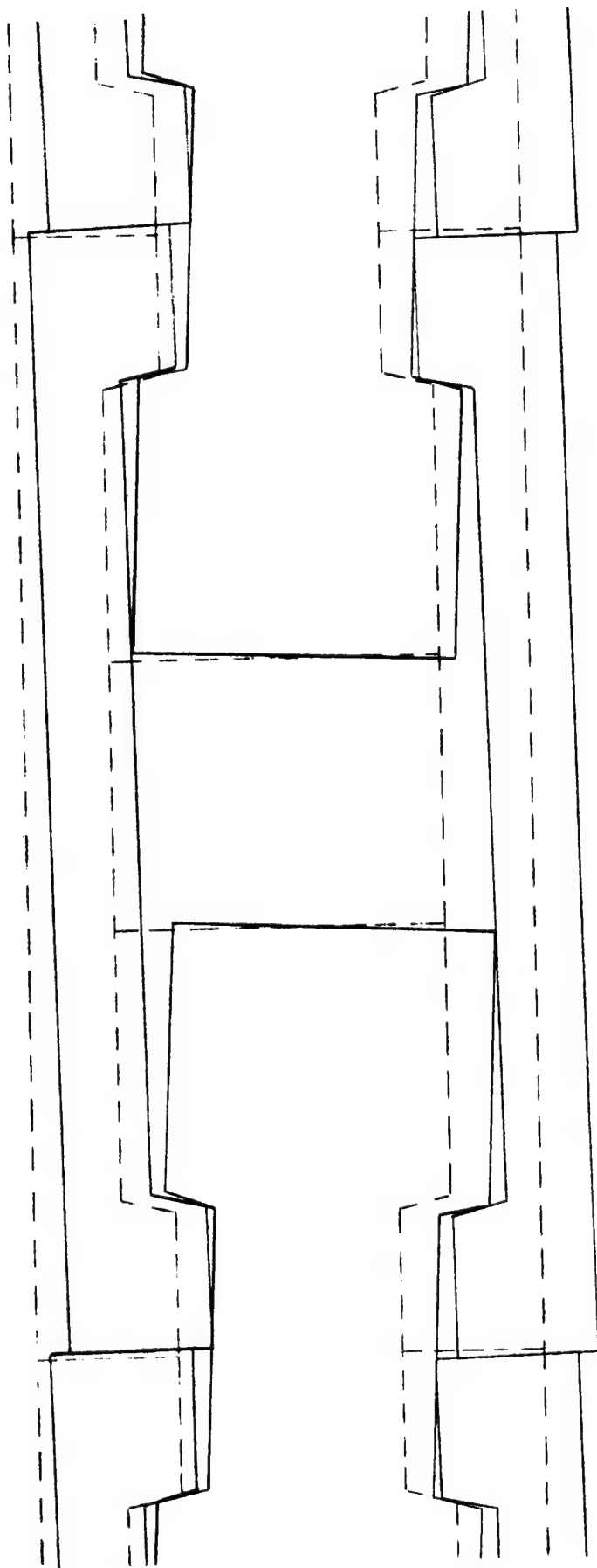


Figure 61



Wrap Vessel Specimen Close-up



← DIR. OF MANDREL
WITHDRAWAL

--- AS WEATHERED ON MANDREL
— CONTACTED POSITION

Figure 63
98

APPENDIX I

STRESS ANALYSIS

CURTISS - WRIGHT CORPORATION
WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

WRITTEN BY L. SEELEN

ENGINE NO.

SHEET _____ OF SHEETS _____

APPROVED BY _____

JOB NO. 51792

DATE 7-18-60

SUBJECT:

INTERLOCKING WIRE WRAP VESSEL

RESULTS, SKETCHES & FORMULAS

APPENDIX A

STRESS ANALYSIS - CALCULATIONS

INTERLOCKING WIRE WRAP VESSEL

RECORD OF ANALYSIS

SHEET a OF SHEETS 28

WRITTEN BY L. SEELEY

APPROVED BY WBS

DATE 3-10-60

ENGINE NO.

JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

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RECORD OF ANALYSIS

SHEET 1 OF SHEETS 23

ENGINE NO.

JOB NO. 51792

SUBJECT:

WRITTEN BY L. SEELEN

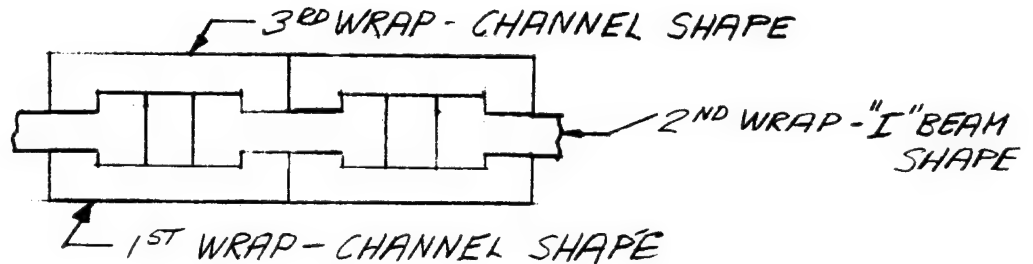
APPROVED BY WBC

DATE 10-19-59

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

DESIRED CONFIGURATION



VESSEL DIAMETER — 6.2"

DESIGN PRESSURE — 5000 psi

MATERIAL

TITANIUM WIRE
B120 VCA

.2% YIELD STRESS

250000 psi (LONGITUDINAL & TRANSVERSE)

MODULUS OF ELASTICITY

15×10^6 psi

ALLOWABLE SHEAR STRESS = $.6 \times 250000 = 150000$ psi

ALLOWABLE BEARING STRESS = $\frac{1.5 \times 250000}{.9} = 416000$ psi

RECORD OF ANALYSIS

SHEET 2 OF SHEETS 28

WRITTEN BY L. SEELEN

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DATE 10-19-59

ENGINE NO.

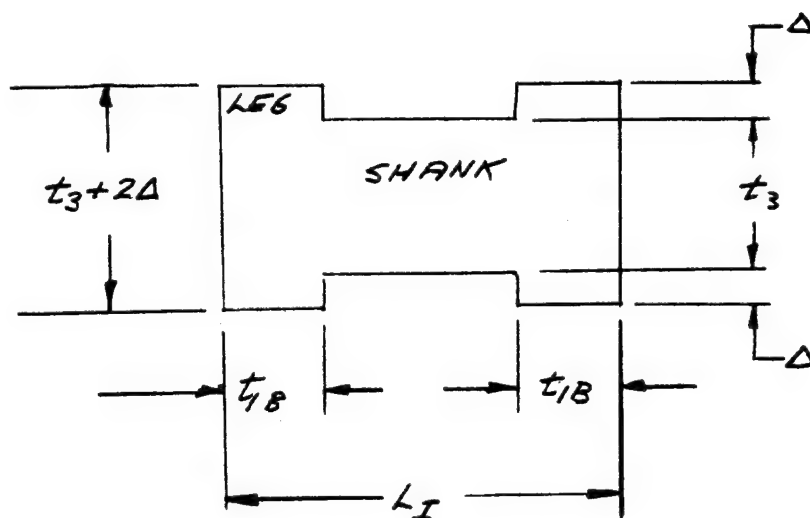
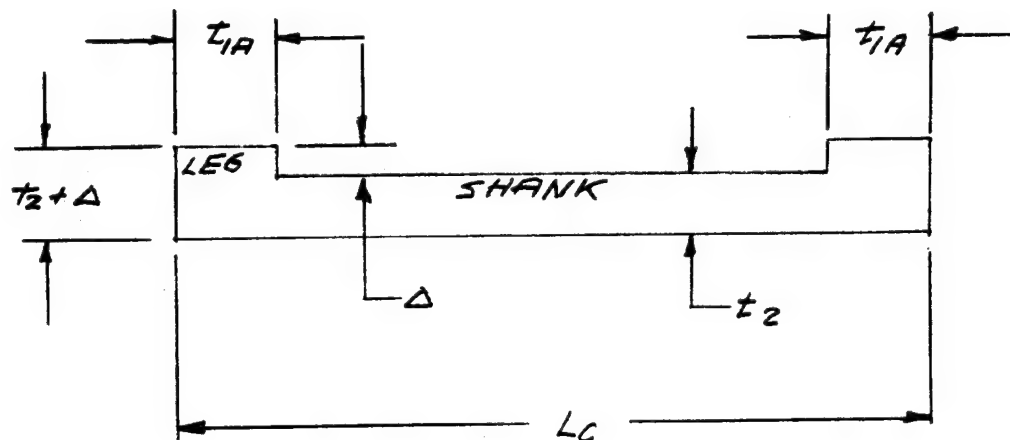
JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

WIRE NOMENCLATURE



RECORD OF ANALYSIS

SHEET 3 OF SHEETS 28

WRITTEN BY L. SEELEN

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DATE 10-20-59

ENGINE NO.

JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

LOADING

$$p = 5000 \text{ psi} \quad D = 6.2''$$

CIRCUMFERENTIAL LOAD

$$= 5000 \frac{\text{#}}{\text{in}^2} \times 3.1 \text{ in} = 15500 \text{ #/in}$$

AXIAL LOAD

$$= \frac{5000 \text{ #/in}^2 \times 3.1 \text{ in}}{2} = 7750 \text{ #/in}$$

BASIC DIMENSIONS - BASED ON AXIAL LOADS

CHANNEL SHAPE

$$2t_2 = \frac{7750}{250000}$$

$$t_2 = .0155 \text{ in}$$

$$2t_{1A} = \frac{7750}{150000}$$

$$t_{1A} = .02583$$

$$2\Delta = \frac{7750}{416000}$$

$$\Delta = .009315$$

DUMBELL SHAPE

$$t_3 = 2t_2$$

$$t_3 = .031 \text{ in}$$

$$t_{1B} = t_{1A}$$

$$t_{1B} = .02583$$

$$\Delta = .009315$$

RECORD OF ANALYSIS

SHEET 4 OF SHEETS 28

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DATE 10-20-59

ENGINE NO.

JOB NO. S1792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BASIC DIMENSIONS (CONTD) - BASED ON CIRCUMFERENTIAL LOADS

THE AREA OF ONE PITCH MUST CARRY THE LOAD/PITCH

$$A_p = 2A_{\text{CHANNEL}} + A_{\text{I}''}$$

$$\text{PITCH LENGTH} = L_c$$

$$\begin{aligned} \text{AREA}_{\text{CHANNEL}} &= 2t_1 \Delta + t_2 L_c \\ &= 2 \times .02583 \times .009315 + .0155 L_c \\ &= .0004812 + .0155 L_c \end{aligned}$$

$$\begin{aligned} \text{AREA}_{\text{I}''\text{SHAPE}} &= 4t_3 \Delta + t_3 L_{\text{I}''} \\ &= .0009624 + .031 L_{\text{I}''} \end{aligned}$$

$$\text{SETTING } L_c = .200 \text{ in}$$

$$A_c = .0004812 + .0031 = .0035812$$

RECORD OF ANALYSIS

SHEET 5 OF SHEETS 28

WRITTEN BY L. SEELEN

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DATE 10-20-59

ENGINE NO.

JOB NO. S1792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BASIC DIMENSIONS (CONTD)

$$.2 \times 15500 = 250000 (.0035812 \times 2 + .0009624 + .0310 \text{ L"} \text{I"})$$

$$\frac{3100}{250000} = .0081248 + .0310 \text{ L"} \text{I"}$$

$$\text{L"} \text{I"} = \frac{.0124 - .0081248}{.031} = \frac{.004275}{.031} = .1379 \text{ in}$$

HOWEVER

THE FIT OF THE CHANNEL LEGS IN THE "I" BEAM
IS TO BE A 1 - 4% PRESS FIT

THEREFOR THE "I" BEAM SHANK MUST BE MADE
HEAVIER TO TAKE THE PRELOAD

RECORD OF ANALYSIS

SHEET 6 OF SHEETS 28

WRITTEN BY L. SEELEN

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DATE 10-20-59

ENGINE NO.

JOB NO. 51792

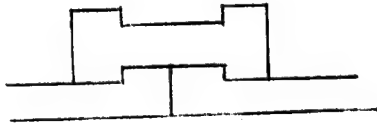
SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

INCREASE t_3 TO .040

1- WRAPPING "I" BEAM LAYER ON 1ST CHANNEL LAYER



TOTAL DEFORMATION = 8 %

$$\text{COMPRESSION OF CHANNEL LEGS} = \frac{-.040}{.040 + .0186} \times 8\% = 5.46\%$$

$$\text{ELONGATION OF "I" BEAM SHANK} = \frac{.0186}{.040 + .0186} \times 8\% = 2.54\%$$

2- WRAPPING 2ND CHANNEL LAYER ON "I" BEAM LAYER

SINCE THE "I" BEAM SHANK HAS ELONGATED 2.54 %

THE TOTAL DEFORMATION DURING THIS WRAP = 5.46 %

FURTHER ELONGATION OF "I" BEAM SHANK

$$= \frac{.0186}{.040 + .0186} \times 5.46\% = 1.633\%$$

RECORD OF ANALYSIS

SHEET 7 OF SHEETS 23

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DATE 10-21-59

ENGINE NO.

JOB NO. S1792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

$$\begin{aligned} \text{TOTAL ELONGATION OF "I" BEAM SHANK} \\ = (2.54 + 1.633) \% = 4.173 \% \end{aligned}$$

THIS IS WITHIN THE ALLOWABLE VALUE, AND ENSURES AGAINST ANY LOSS OF PRELOAD DUE TO PRESSURIZATION SINCE THE PRESSURE LOAD NEVER EXCEEDS THE PRELOAD, THE CHANNEL LEGS REMAIN BUTTED, AND NEITHER THE CHANNEL LEGS NOR THE "I" BEAM LEGS ARE SUBJECT TO BENDING STRESSES.

RE-SIZE "I" BEAM

ALL DIMENSIONS EXCEPT L_I REMAIN

$$L_I = \frac{-.031}{.040} \times .1379 = .1069 \text{ in}$$

RECORD OF ANALYSIS

SHEET 8 OF SHEETS 28

WRITTEN BY L. SEELIN

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DATE 10-21-59

ENGINE NO.

JOB NO. S1792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

FINAL SIZE

CHANNEL

$$t_2 = .0155$$

$$t_{1A} = .026$$

$$\Delta = .0093$$

$$L_c = .200$$

1" BEAM

$$t_3 = .040$$

$$t_{1B} = .026 *$$

$$\Delta = .0093$$

$$L_I = .1069$$

* SEE PP 10 & 15, CASE 1B, FOR SUGGESTED INCREASE TO .040 in.

RECORD OF ANALYSIS

SHEET 9 OF SHEETS 28

ENGINE NO.

JOB NO. S1792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

WRITTEN BY L-SEELEN

APPROVED BY WBG

DATE 10-21-59

RESULTS, SKETCHES & FORMULAS

IF THE "I" BEAM SHAPE DOES NOT BOTTOM ON CHANNEL WRAP
THE SPAN IS .1472 IN. THE DEFLECTION OF THE CHANNEL
.025 IN FROM THE END

$$= \frac{5000 \times .025^2 (.1472 - .025)^2}{24 \times 15 \times 10^6 \times .0155^3} \times 12 = .000417 \text{ IN.}$$

IF THE "I" BEAM LEG HEIGHTS ARE MIN
AND THE CHANNEL LEG HEIGHTS ARE MAX
THE CLEARANCE IS .0004 IN.

DEFORMATION DUE TO THE PRESS FIT CAUSES THE CLEARANCE
TO APPROACH ZERO, AND THE ANALYSIS ASSUMING THE
DISTANCE BETWEEN "I" BEAMS AS THE CHANNEL SPAN
IS ESSENTIALLY CORRECT

A MORE ACCURATE METHOD ASSUMES A FIXED BEAM
WITH THE .1472" SPAN LENGTH SIMPLY SUPPORTED .025"
FROM EITHER END.

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WRIGHT AERONAUTICAL DIVISION
RECORD OF ANALYSIS
SHEET 10 OF SHEETS 28

ENGINE NO.

JOB NO. S1792

SUBJECT:

INTERLOCKING WIRE WRAP VESSEL

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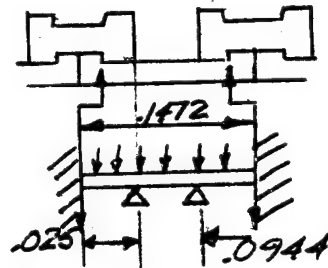
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DATE 10-21-59

RESULTS, SKETCHES & FORMULAS

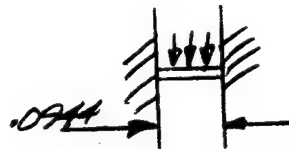
ASSUMED CONFIGURATIONS

CASE 1A — FIXED ENDED - SIMPLY SUPPORTED AT
"I" BEAM ENDS



CASE 1B — SAME AS 1A EXCEPT $.025 = .040$

CASE 2A, 2B — FIXED ENDED AT "I" BEAM ENDS



RECORD OF ANALYSIS

SHEET 11 OF SHEETS 28

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DATE 10-22-59

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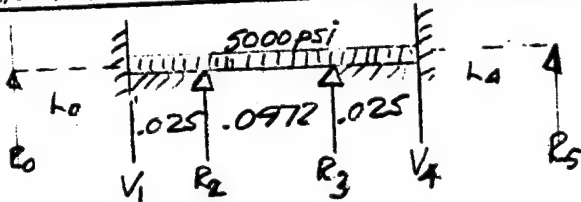
JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP UNDER PRESSURE - CASE 1a



THREE MOMENT METHOD

SPAN 0-1

$$\textcircled{1} M_0 h_0 + 2 M_1 (L_0 + h_1) + M_2 L_1 + \frac{6 A_0 \bar{a}_0}{L_0} + \frac{6 A_1 \bar{b}_1}{L_1} = 0$$

SPAN 1-2

$$\textcircled{2} M_1 L_1 + 2 M_2 (L_1 + L_2) + M_3 L_2 + \frac{6 A_1 \bar{a}_1}{L_1} + \frac{6 A_2 \bar{b}_2}{L_2} = 0$$

SPAN 2-3

$$\textcircled{3} M_2 L_2 + 2 M_3 (L_2 + L_3) + M_4 L_3 + \frac{6 A_2 \bar{a}_2}{L_2} + \frac{6 A_3 \bar{b}_3}{L_3} = 0$$

SPAN 3-4

$$\textcircled{4} M_3 L_3 + 2 M_4 (L_3 + L_4) + M_5 L_4 + \frac{6 A_3 \bar{a}_3}{L_3} + \frac{6 A_4 \bar{b}_4}{L_4} = 0$$

IN APPLYING THESE EQUATION ALL TERMS REFERRING TO THE
IMAGINARY SPANS ARE NEGLECTED.

RECORD OF ANALYSIS

SHEET 12 OF SHEETS 28

ENGINE NO.

JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

WRITTEN BY L. SEELEN

APPROVED BY WPG

DATE 10-22-59

RESULTS, SKETCHES & FORMULAS

$$\frac{6 A_1 \bar{b}_1}{L_1} = \frac{5000 \times .025^3}{4} = .01954$$

$$\frac{6 A_1 \bar{a}_1}{L_1} = \frac{5000 \times .025^3}{4} = .01954$$

$$\frac{6 A_2 \bar{b}_2}{L_2} = \frac{5000 \times .0972^3}{4} = 1.1479$$

$$\frac{6 A_2 \bar{a}_2}{L_2} = \frac{5000 \times .0972^3}{4} = 1.1479$$

$$\frac{6 A_3 \bar{b}_3}{L_3} = \frac{5000 \times .025^3}{4} = .01954$$

$$\frac{6 A_3 \bar{a}_3}{L_3} = \frac{5000 \times .025^3}{4} = .01954$$

- $$\begin{aligned} \textcircled{1} \quad 2M_1(.025) + M_2(.025) + .01954 &= 0 \\ \textcircled{2} \quad M_1(.025) + 2M_2(.1222) + M_3(.0972) + .01954 + 1.1479 &= 0 \\ \textcircled{3} \quad M_2(.0972) + 2M_3(.1222) + M_4(.025) + .01954 + 1.1479 &= 0 \\ \textcircled{4} \quad M_3(.025) + 2M_4(.025) + .01954 &= 0 \end{aligned}$$
-
- $$\begin{aligned} \textcircled{1} \quad .050 M_1 + .025 M_2 + .01954 &= 0 \\ \textcircled{2} \quad .025 M_1 + .2444 M_2 + .0972 M_3 + 1.16744 &= 0 \\ \textcircled{3} \quad .0972 M_2 + .2444 M_3 + .025 M_4 + 1.16744 &= 0 \\ \textcircled{4} \quad .025 M_3 + .05 M_4 + .01954 &= 0 \end{aligned}$$

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 13 OF SHEETS 28

ENGINE NO.

JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

WRITTEN BY L. SEELEN

APPROVED BY W.B.G.

DATE 10-22-59

RESULTS, SKETCHES & FORMULAS

M_1

M_2

M_3

M_4

K

①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
⑭
⑮
⑯
⑰

	.050	.025			-.01954
$\frac{.025}{.050} = .5$	.025	.2444	.0972		-1.16744
$-.5 \times ①$	-.025	-.0125			+.00977
② + ③	0	.2319	.0972		-1.15767
		.0972	.2224	.025	-1.16744
	-	-	-	-	-
⑤ + ⑥ $\frac{.0972}{.2315} = .4142$		.0972	.2444	.025	-1.16744
$-.4142 \times ④$		-.0972	-.0407	-	+.48530
⑦ + ⑧		0	.2037	.025	-.68214
			.025	.050	-.01954
	-	-	-	-	-
⑩ + ⑪			.025	.050	-.01954
	-	-	-	-	-
⑬ + ⑭ $\frac{.025}{.1816} = .1377$			.025	.050	-.01954
$-.1377 \times ⑨$			-.025	-.00344	+.09382
			0	.04656	.07428

RECORD OF ANALYSIS

SHEET 11 OF SHEETS 28

ENGINE NO.

JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

WRITTEN BY L. SEELEN

APPROVED BY WBC

DATE 10-22-59

RESULTS, SKETCHES & FORMULAS

$$M_4 = .07428 / .04656 = +1.5954$$

$$M_3 = \frac{-.68214 - .025 \times 1.5954}{.2037} = -3.5446$$

$$M_2 = \frac{-1.15767 + .0972(3.5446)}{.2319} = -3.5064$$

$$M_1 = \frac{-.01954 + .025(3.5064)}{.050} = +1.3624$$

HOWEVER M_1 SHOULD EQUAL M_4 AND $M_2 = M_3$

THE DISCREPANCY IS DUE TO THE NUMBER OF CALCULATIONS PERFORMED

ASSUME

$$M_1 = M_4 = \frac{1.5954 + 1.3624}{2} = 1.4788 \text{ in-lb/in}$$

$$M_2 = M_3 = \frac{-(3.5064 + 3.5446)}{2} = -3.5255 \text{ in-lb/in}$$

$$S_{b1} = 6 \times 1.4788 / .0155^2 = \underline{36900}$$

$$S_{b2} = 6 \times 3.5255 / .0155^2 = \underline{88000}$$

RECORD OF ANALYSIS

SHEET 15 OF SHEETS 28

WRITTEN BY L. SEELIN

APPROVED BY WBS

DATE 10-23-59

ENGINE NO.

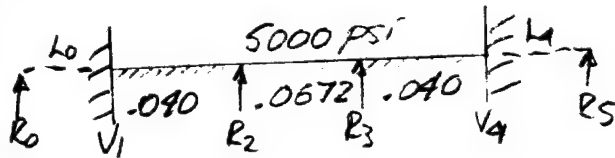
JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED MOTOR

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP UNDER PRESSURE - CASE 16



$$\frac{5000 \times .040^3}{4} = -.03$$

$$-.03 + .3793 = .4093$$

$$\frac{5000 \times .0672^3}{4} = .3793$$

$$\textcircled{1} .080 M_1 + .040 M_2 = -.03$$

$$\textcircled{2} .040 M_1 + .2144 M_2 + .0672 M_3 = -.4093$$

BY SYMMETRY $M_2 = M_3$

$$\textcircled{1} .080 M_1 + .040 M_2 = -.03$$

$$\textcircled{2} .040 M_1 + .2816 M_2 = -.4093$$

$$\textcircled{3} .040 M_1 + .0200 M_2 = -.0150$$

$$\textcircled{3} \quad .2616 M_2 = -.3943$$

$$M_2 = \underline{-1.507}$$

$$M_1 = \frac{-.03 + .04 \times 1.507}{.08} = \underline{\underline{.3785}}$$

$$S_{b1} = \frac{6 \times .3785}{.0155^2} = 9440 \text{ psi}$$

$$S_{b2} = \frac{6 \times 1.507}{.0155^2} = 37600 \text{ psi}$$

RECORD OF ANALYSIS

SHEET 16 OF SHEETS 28

ENGINE NO.

JOB NO. S1792

SUBJECT:

WRITTEN BY L. SEELEN

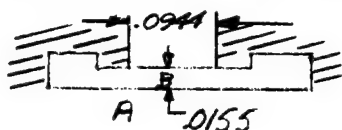
APPROVED BY W. B. G.

DATE 10-23-59

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP DUE TO PRESSURE - CASE 2 a



TREATING THE CHANNEL AS A FIXED ENDED BEAM WHERE
"A" IS AT THE SUPPORT AND "B" IS AT THE CENTER.

$$M''_A = \frac{p(.0944)^2}{12} = .0007426 p$$

$$I = \frac{1 \times .0155^3}{12} = .4 \times 10^{-4}$$

$$M''_B = \frac{p(.0944)^2}{24} = .0003713 p$$

$$S_b''_A = .0007426 p / .00004 = 18.565 p = \underline{93000 \text{ psi}}$$

$$S_b''_B = .0003713 p / .00004 = 9.283 p = \underline{46500 \text{ psi}}$$

WITH A SUBSCALE VESSEL SUCH AS THE ONE CURRENTLY
UNDER DEVELOPMENT, THE BENDING STRESSES IN THE
1ST CHANNEL WRAP WILL BE LARGE.

HOWEVER FULL SCALE VESSELS OPERATE AT SUBSTANTIALLY

LOWER PRESSURES AND THIS STRESS IS NEGLIGIBLE.

THE CHANGE IN "I" BEAM WIDTH SUGGESTED ON PAGE 15

WILL REDUCE THESE STRESS TO 43000 psi AT THE END

AND 21600 psi AT THE CENTER (CASE 2B)

RECORD OF ANALYSIS

SHEET 17 OF SHEETS 28

WRITTEN BY L. SEELEN

APPROVED BY WBS

DATE 10-23-59

ENGINE NO.

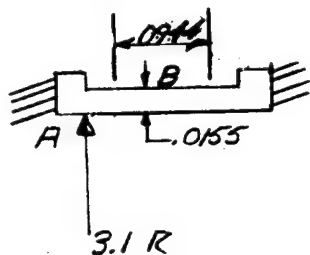
JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP UNDER PRESSURE - CASE 3



FIXED ENDED BEAM ON ELASTIC FOUNDATION

$$\lambda = 1.285 \sqrt{3.1 \times 0.0155} = 5.868$$

$$\lambda L = 5.868 \times 0.0944 = .55$$

$$\lambda^2 = 34.433$$

$$M_A = -\frac{P}{2\lambda^2} \left[\frac{\sinh \lambda L - \sin \lambda L}{\sinh \lambda L + \sin \lambda L} \right] \quad \text{MOMENT AT ENDS } 2 - \frac{.0264}{1} = .0944$$

$$M_B = \frac{P}{\lambda^2} \left[\frac{\sin \frac{\lambda L}{2} \cosh \frac{\lambda L}{2} - \cos \frac{\lambda L}{2} \sinh \frac{\lambda L}{2}}{\sinh \lambda L + \sin \lambda L} \right] \quad \text{MOMENT AT CENTER}$$

for $\lambda L = .55$

$$M_A = \frac{-5000}{2 \times 34.433} \left\{ \frac{.5782 - .5227}{.5782 + .5227} \right\} = -3.67 \text{ in-lb/in}$$

$$M_B = \frac{-5000}{34.433} \left\{ \frac{-.2764 \times 1.0395 - .9611 \times .2837}{1.1009} \right\} = 1.93 \text{ in-lb/in}$$

$$\sigma_{MA} = \frac{6 \times -3.67}{.0155^2} = 91660 \text{ psi}$$

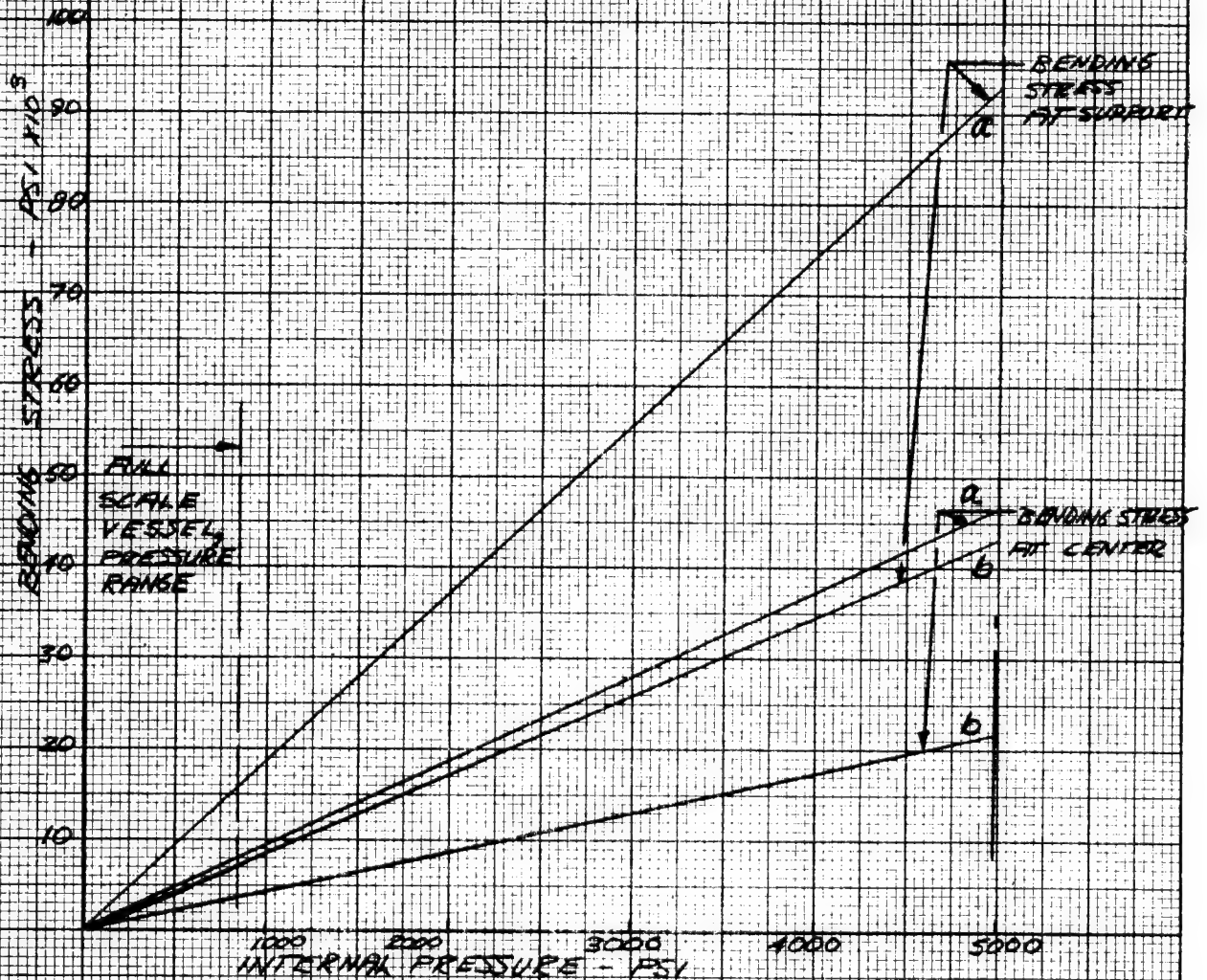
$$\sigma_{MB} = 18200 \text{ psi}$$

NOTE: COMPARISON OF THESE STRESSES WITH THOSE OF CASE 2b SHOWS A NEGLIGIBLE REDUCTION IN BENDING STRESS RESULTING FROM CONSIDERATION OF VESSEL CURVATURE

M. Hetenyi - Beams on Elastic Foundations

INTERLOCKING WIRE WRAPPED VESSEL
(6IN. SUBSCALE)

BENDING OF 1ST CHANNEL WRAP - CASE 2a & 2b



A. SELEN

10/23/59
WBG

RECORD OF ANALYSIS

SHEET 19 OF SHEETS 28

WRITTEN BY D. Kanowsky

APPROVED BY WBC

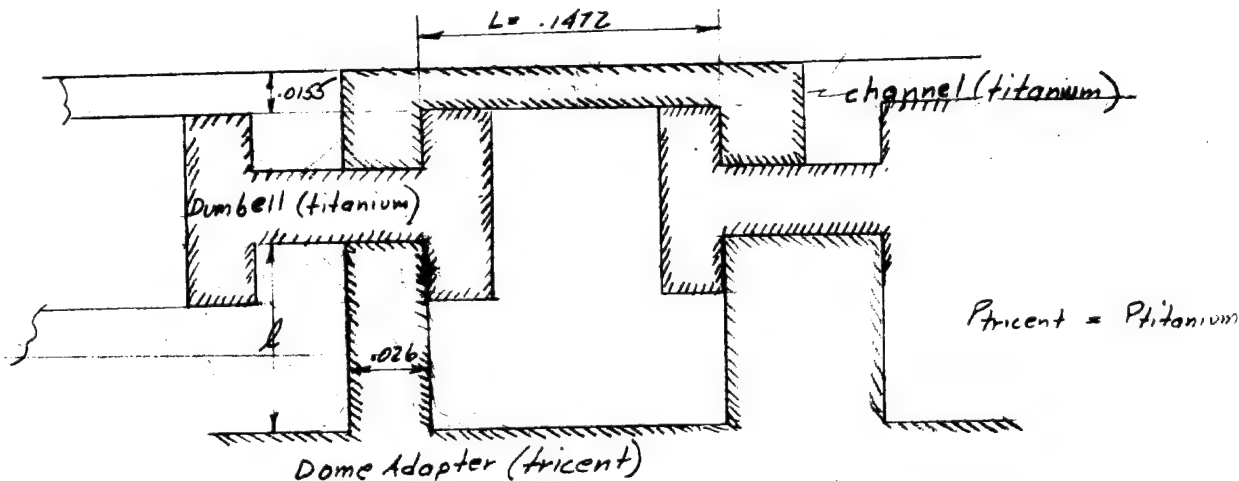
DATE 2/19/60

ENGINE NO. Wire wrap Motor

JOB NO. 51792

SUBJECT: Dome Adapter stresses

RESULTS, SKETCHES & FORMULAS



$$\Sigma \delta_{tr} = \delta_c$$

$$\left(\frac{PL^3}{3EI} + \frac{6}{5} \frac{PL}{AG} \right)_{tr} = \left(\frac{PL}{AE} \right)_c$$

$$\frac{l^3}{3(30)(1.30)} + \frac{6}{5} \frac{l}{(.026)(12 \times 10^6)} = \frac{.1472}{(.0155)(16 \times 10^6)}$$

$$.00854l^3 + 3.85 \times 10^{-6} l = .594 \times 10^{-6}$$

$$l^3 + 4.51 \times 10^{-4} l = .697 \times 10^{-4}$$

$$l = .037 \text{ (say } .035 \text{")}$$

$$P_{total} = 7750 \text{ #/in} \quad P_{tr} = P_c = 3875 \text{ #} \checkmark$$

trident: $M = 3875 \times .035 = 136$

$$\frac{I}{E} = \frac{1.30 \times 10^{-6}}{1.3 \times 10^{-2}} = 1 \times 10^{-4}$$

$$\sigma = \frac{136}{1} \times 10^4 = 116H$$

shear

$$\sigma = \frac{3875}{.026} = 149,000 \text{ psi}$$

if trident is assumed to be prevented from bending, by the abutting channel:

$$\text{then: } 3.85l = .594$$

$$l = .155$$

RECORD OF ANALYSIS

SHEET 20 OF SHEETS 28

ENGINE NO. Wire Wrap Motor

JOB NO. 51792

SUBJECT: Trial & Error solution for "l"

WRITTEN BY D. Kanowsky

APPROVED BY WBB

DATE 2/19/60

RESULTS, SKETCHES & FORMULAS

$$l^3 + 4.51 \times 10^{-4} l = .697 \times 10^{-4}$$

l	.02	.03	.04	.035	.037	.038
l^3	$.08 \times 10^{-4}$	$.27 \times 10^{-4}$	$.64 \times 10^{-4}$	$.43 \times 10^{-4}$	$.507 \times 10^{-4}$	$.549 \times 10^{-4}$
$+ 4.51 l \times 10^{-4}$	$.090 \times 10^{-4}$	$.135 \times 10^{-4}$	$.1804 \times 10^{-4}$	$.158 \times 10^{-4}$	$.167 \times 10^{-4}$	$.171 \times 10^{-4}$
$= .697 \times 10^{-4}$	$.17 \times 10^{-4}$	$.405 \times 10^{-4}$	$.82 \times 10^{-4}$	$.588 \times 10^{-4}$	$.674 \times 10^{-4}$	$.720 \times 10^{-4}$

$$l = .037$$

RECORD OF ANALYSIS

SHEET 21 OF SHEETS 28

ENGINE NO. Wire Wrap Motor

JOB NO. 5792

SUBJECT: Dome Adapter stress

WRITTEN BY D. Kanowsky

APPROVED BY W.B.G.

DATE 2/19/60

RESULTS, SKETCHES & FORMULAS

$$l = .035$$

Tolerance condition when trident is stiffest:

	titanium	trident
A	.0145	.0268
E	16×10^6	30×10^6
G		12×10^6
l	.15	.035
I		$\frac{1}{12} (.0268)^3 = 1.61 \times 10^{-6}$

$$P_T \left[\frac{(.035)^3}{3(30)(1.61)} + \frac{.035}{5(.0268)(12 \times 10^6)} \right] = P_c \left(\frac{.15}{(.0145)(16 \times 10^6)} \right)$$

$$P_T [.297 \times 10^{-6} + .130 \times 10^{-6}] = P_c (.648 \times 10^{-6})$$

$$P_T (.427) = P_c (.648)$$

$$P_T = 1.52 P_c$$

$$\text{total } P = 7750^*$$

$$P_T = 4670^*$$

$$P_c = 3080^*$$

$$\text{Trident: } \frac{I}{C} = \frac{1.61 \times 10^{-6}}{1.34 \times 10^{-2}} = 1.2 \times 10^{-4}$$

$$M = 4670 \times .035 = 163$$

$$\sigma = \frac{163}{1.2} \times 10^4 = \text{High}$$

Shear.

$$\sigma = \frac{4670}{.0268} = 174,000 \text{ psi}$$

$$\text{Titanium: } S = \frac{P}{A} = \frac{3080}{.0145} = 210,000$$

$$E = \frac{S}{\epsilon} = \frac{210,000}{.013} = \frac{.21}{16} = .013$$

RECORD OF ANALYSIS

SHEET 22 OF SHEETS 28

WRITTEN BY D. Kanewsky

APPROVED BY W.B.G.

DATE 2/18/60

ENGINE NO.

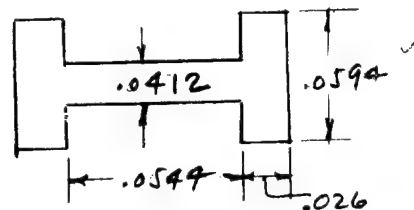
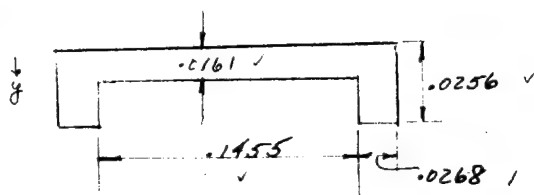
JOB NO. S1792

SUBJECT: wire wrapped Motor
stress in wire on spool.

RESULTS, SKETCHES & FORMULAS

wire to be unwrapped from 6" spool:

Bending stress:



$$\frac{M}{EI} = \frac{1}{R}$$

$$M = \sigma_p I = \sigma \frac{I}{k}$$

$$\frac{\sigma \frac{I}{k}}{EI} = \frac{1}{R}$$

$$I = \frac{CE}{R} \checkmark$$

channel:

$$E = 16 \times 10^6 \text{ psi}$$

$$R = 3.1''$$

	x	y	Ay
$.0161 \times .1455$	$= .00234$	$.0080$	$.0000187 \checkmark$
$2 \times .0256 \times .0268$	$= .00137$	$.0128$	$.0000175$
	$.00371$		$.0000362$

$$\bar{y} = \frac{.0000362}{.00371}$$

$$\bar{y} = c_1 = .00974 \checkmark$$

$$c_2 = .0256 - .00974$$

$$c_2 = .0159 \checkmark$$

$$\sigma = \frac{(.0159) 16 \times 10^6}{3.1}$$

$$\sigma = 82,000 \text{ psi}$$

NG reduce to 50,000 psi max \checkmark

$$\sigma = (50,000) = \frac{(.0159) 16 \times 10^6}{R}$$

$$\text{min. } R = \frac{(.0159) 16 \times 10^6}{50 \times 10^3} = 5.05'' \checkmark$$

10.1" spool \checkmark

Dumbell.

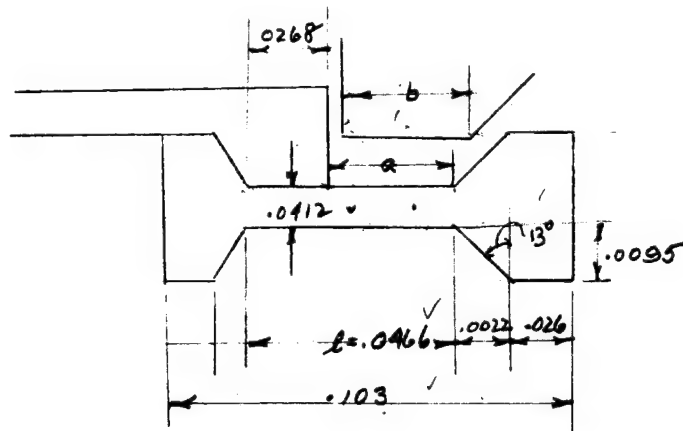
$$c_1 = c_2 = .0297'' \checkmark$$

$$\sigma = \frac{.0297}{.0159} \times 82,000 = 153,000 \text{ psi}$$

$$\text{min } R \text{ for } 50,000 \text{ psi} = \frac{.0297}{.0159} \times 5.05 = 9.43''$$

use 19" spool \checkmark

Force req'd to place wire



$$.0095 \tan 13^\circ = .0095(.231)$$

$$= .0022$$

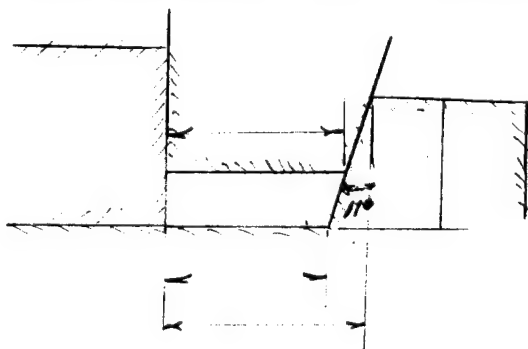
$$\begin{array}{r} .103 \\ - .052 = 2 \times .026 \\ \hline .051 \\ - .0044 = 2 \times .002 \\ \hline l = .0466 \\ - .0268 \\ \hline .0198 = q \end{array}$$

$$\begin{array}{r} b = .0268 \\ a = .0198 \\ \hline \delta = .0070'' \end{array}$$

$$\delta = \frac{Pl}{AE} \quad P = \frac{AE \delta}{l}$$

Horizontal Force $P = \frac{(.0412)(16 \times 10^6)(.007)}{.0466} = 98,800^{\#} \checkmark$

if deformation of other parts are considered, P will be reduced by about 60%. Assume $P = 40,000$ * ✓



RECORD OF ANALYSIS

SHEET 24 OF SHEETS 28

WRITTEN BY D. Kanowsky

APPROVED BY W.B.G.

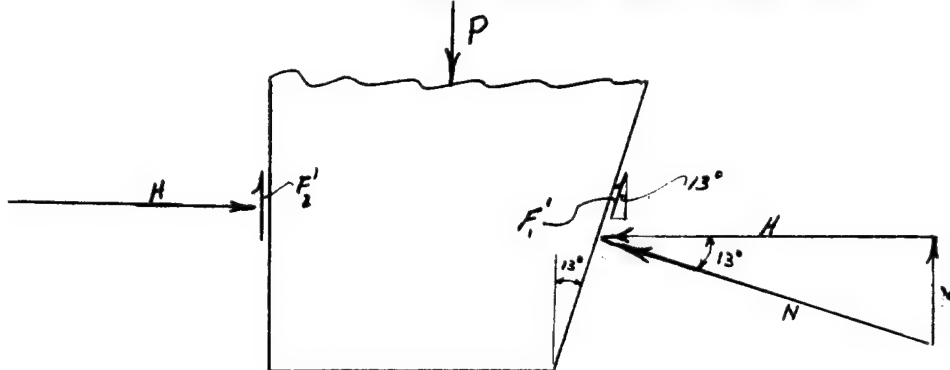
DATE 2/23/60

ENGINE NO. Wire wrap

JOB NO. 51792

SUBJECT: Force req'd to place wire

RESULTS, SKETCHES & FORMULAS



$$P = H \tan 13^\circ + F_1' \cos 13^\circ + F_2'$$

$$F_1' = \mu N = \frac{H}{\cos 13^\circ}$$

$$F_2' = \mu H$$

$$P = H [\tan 13^\circ + 2\mu]$$

$$H = 40,000^* \text{ per inch circumference}$$

$$\mu = .2 \text{ (assumed)}$$

$$\tan 13^\circ = .231$$

$$\tan 13^\circ = .231$$

$$2\mu = \frac{.400}{.631} \times 40,000$$

$$P = 25,000^* \text{ /inch of circum.}$$

assume length of contact between roller & wire = .1"

$$P = .1 \times 25000$$

apply P = 2500^* ✓

RECORD OF ANALYSIS

SHEET 25 OF SHEETS 28

WRITTEN BY D. Konowsky

APPROVED BY WBG

DATE 3/8/60

ENGINE NO. Wire Wrap

JOB NO. S1792

SUBJECT: Axial Pull for Wrapping Wire

RESULTS, SKETCHES & FORMULAS

Spool Diameter 7"

Vessel Diameter 6.5"

$$\frac{M}{EI} = \frac{1}{R}$$

$$\sigma_b = \frac{MC}{I} = \frac{EI}{R} \cdot \frac{C}{I} = \frac{EC}{R}$$

$$\text{Hold } \sigma \text{ to } .70 \sigma_y = .70 \times 250,000 = 175,000 \text{ psi}$$

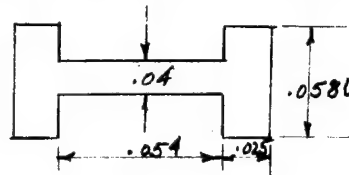
$$\sigma = \sigma_b + \sigma_a$$

$$\sigma = \frac{EC}{R} + \frac{P}{A} \leq 175,000$$

Dumbell

$$c = .0297''$$

$$A = .00509''$$



$$\text{Area: } .04 \times .0586 = .00216$$

$$+ 2 \times .025 \times .0586 = .00293$$

$$A = .00509$$

$$\text{unwinding: } \frac{EC}{R} = \frac{16 \times 10^6 \times .0297}{3.5} = 135,500 \text{ psi}$$

$$\frac{P}{A} = 175,000 - 135,500 = 39,500 \text{ psi}$$

$$P \leq 39,500 \times .00509$$

$$\underline{P \leq 201''}$$

channel

$$\text{max } c = .016''$$

$$A = .0037''$$

$$\frac{EC}{R} = \sigma_b = \frac{.016}{.0297} \times 135,500 = 73,000 \text{ psi}$$

$$\frac{P}{A} = 175,000 - 73,000 = 102,000 \text{ psi}$$

$$P \leq 102,000 \times .0037$$

$$\underline{P \leq 377''}$$

RECORD OF ANALYSIS

SHEET 26 OF SHEETS 28WRITTEN BY D. KanowskyAPPROVED BY WBGDATE 3/17/60ENGINE NO. Wire WrapJOB NO. 51792SUBJECT: Axial Pull for Wrapping wire

RESULTS, SKETCHES & FORMULAS

unwrapping wire from 7" spool:

Dumbell $\sigma = 135,500 \text{ psi}$ channel $\sigma = 73,000 \text{ psi}$

wire to be rewound on 6.5" diameter vessel

Dumbell:

$$\sigma' = \frac{EC}{R} = \frac{16 \times 10^6 \times .0297}{3.25} = 146,000 \text{ psi}$$

channel

$$\sigma' = \frac{16 \times 10^6 \times .016}{3.25} = 78,700 \text{ psi}$$

stresses remaining in wire due to wrapping:

Dumbell:

wrap on 6.5"	146,000
unwrap from 7.0"	<u>135,500</u>
net stress	<u>10,500 psi</u>

Channel:

wrap on 6.5"	78,700
unwrap from 7.0"	<u>73,000</u>
net stress	<u>5,700 psi</u>

To keep total preload in wire below 50,000 psi:

Dumbell $50,000 - 10,500 = 39,500$ use $P \leq 200^*$ as beforechannel $50,000 - 5,700 = 44,300$

$$44,300 = \frac{P}{A}$$

$$P = 44,300 \times .0037 = 165^*$$

This assumes full axial load will remain in wire.

Recommend $\max P = 200^*$ for Dumbell & Channel

RECORD OF ANALYSIS

SHEET 27 OF SHEETS 28

WRITTEN BY D. Kanowsky

APPROVED BY WBC

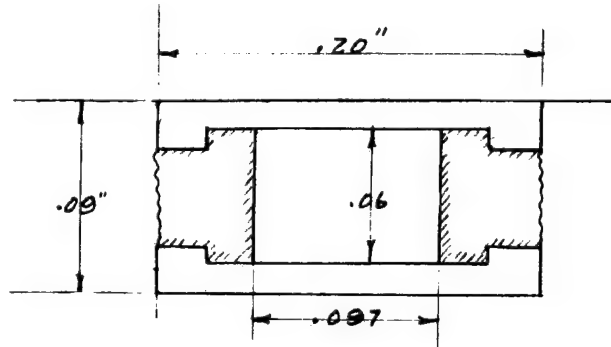
DATE 3/8/60

ENGINE NO. Wire Wrap

JOB NO. S1792

SUBJECT: End Taper on Dome Adapter Piece

RESULTS, SKETCHES & FORMULAS



Effective thickness of wire assembly:

$$\begin{aligned} \text{Area in } .20" \text{ length: } & .09 \times .20 = .0180 \\ & - .097 \times .06 = \underline{.0058} \\ & .0122 \end{aligned}$$

$$\text{Area per inch} = .0122 \times \frac{1}{.20} = .061"$$

$$\text{Effective thickness} = .061"$$

$$\text{use thickness at end of } \overset{\text{trient}}{\Lambda} \text{ taper: } \underline{\underline{t = .025"}}$$

Thickness for yielding of trient at 5000 psi pressure:

$$\frac{pR}{t} = \sigma_y \quad t = \frac{pR}{\sigma_y} \quad \sigma_y = 220,000 \text{ psi}$$

$$t = \frac{5000 \times 3.25}{220,000} = .074 \sim \underline{\underline{.075}}$$

RECORD OF ANALYSIS

SHEET 28 OF SHEETS 28

ENGINE NO. Wire Wrap

JOB NO. 51792

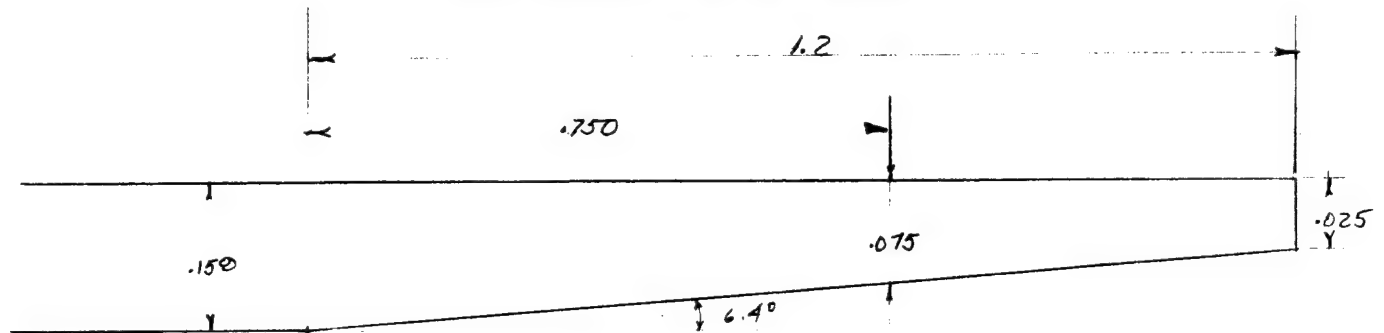
SUBJECT: End Taper on Dome Adapter Piece

WRITTEN BY D. Konowsky

APPROVED BY WBC

DATE 3/8/60

RESULTS, SKETCHES & FORMULAS



$$\frac{.075 - .025}{.159 - .075} \times .750 = .415$$

$$\frac{.159 - .025}{1.2} = \tan \alpha = \frac{.134}{1.2} = .1118$$

$$\alpha = 6.4^\circ$$

The .025 end thickness and .75 length were arbitrarily chosen. The adapter will yield from the .75 length to the .025 end, thus reducing the effects of the interlocking wire wrapped cylinder - adapter discontinuity.

Memo: Leprete to Lorsch 2/10/60

APPENDIX II

STRUCTURAL RIG TESTING PROCEDURE

1. Instrument the specimen as shown in Figure 16 and check.
2. Balance all gages. Take a zero and a calibration reading.
3. A combination of three loads is to be applied to the specimen for each reading of strain values. These are the tensile, the longitudinal clamping load from the torquing of the two 7/8 in. side bolts, and the transverse clamping load induced by torquing the two 1/4 in. top bolts. For each combination of pull load and transverse clamping load, three longitudinal clamping loads are applied.

A typical cycle in applying the loads is as follows:

- (a) Torque 1/4 in. transverse clamping bolts to 4 in. lbs. Apply 4,650 lbs. tensile load to specimen and record strain readings. Release the load.
 - (b) Using the same transverse clamping load as in step (a), apply 489 in. lbs. torque on the 7/8 in. longitudinal clamping bolts. Apply the same load as in step (a) and record the strain readings. Release the load. (c) repeat step (c) using 586 in. lbs. torque on the 7/8 in. longitudinal clamping bolts.
4. Tabulation of the test loads and the order of their application are as follows:

APPENDIX II (Continued)

<u>Longitudinal Clamping Load (lbs.)</u>		<u>Equiv. (Approx.) 7/8 in Bolt Torque (in.lbs.)</u>	<u>Tensile Load (lbs.)</u>	<u>Trans. Clamp Load (lbs.)</u>	<u>Equiv. (Approx.) 1/4 in Bolt Torque (in.lbs.)</u>
(a)	2360	391	4,650	81	4
(b)	2950	489			
(c)	3540	486			
(a)	3930	651	7,750	135	6
(b)	4910	813			
(c)	5880	974			
(a)	5490	909	10,850	189	9
(b)	6860	1136			
(c)	8230	1363			
(a)	7050	1167	13,950	243	11
(b)	8840	1464			
(c)	10600	1755			
(a)	8650	1432	17,050	297	14
(b)	10800	1799			
(c)	12820	2123			
(a)	10250	1697	20,150	351	16
(b)	12750	2111			
(c)	15400	2550			

APPENDIX III

B12OVCA TITANIUM WIRE SPECIFICATION

1. ACKNOWLEDGEMENT: Vendor shall mention the specification number and its revision letter in all quotations and when acknowledging purchasing orders.

2. FORM: Coils of wire.

3. COMPOSITION:

		<u>CHECK ANALYSIS</u>	
		<u>Under Min. or Over Max.</u>	
Vanadium	12.5-14.5	0.15	0.15
Chromium	10.00-12.00	0.15	0.15
Aluminum	3.0-4.0	0.40	0.40
Oxygen	0.15-Max.	-	-
Carbon	0.06-Max.	-	0.02
Nitrogen	0.05-Max.	-	0.02
Hydrogen	0.0100-Max.	-	.001
Other Elements	0.060-Max.	-	-
Iron	0.35-Max.	-	0.05
Titanium	balance	-	-

4. CONDITION:

- 4.1 Uniformly solution annealed after final draw.
- 4.2 Material shall be free from all surface and sub-surface defects.
- 4.3 No surface contamination or oxide film.
- 4.4 Wire shall be coil ground before final draw.
- 4.5 Wire shall contain no seams, nicks, kinks, bends, breaks, burrs, scratches, or marks due to grinding or drawing.
- 4.6 Wire surface must be clean and contain no foreign materials and imperfections which may adversely affect the processing or quality of finished articles.

APPENDIX III (Continued)

5. TOLERANCES: Unless otherwise specified, tolerances shall conform to the following:

Diameter	Nominal	Inch	Tolerances, Inch	
			<u>Plus</u>	<u>Minus</u>
.130	-	.200	0.001	0.001
.121	-	.130	0.000	0.0005
		0.120	0.0005	0.0005

6. TENSILE PROPERTIES:

Tensile strength, psi	130,000 min.
Reduction in area, %	25 min.

7. REPORTS: Unless otherwise specified, the vendor of wire shall furnish with each shipment three copies of a report of the results of tests for chemical composition and tensile strength of each coil in the shipment. This report shall include the purchase order, heat number, material specification number, size, and quantity.
8. PACKAGING: Packaging shall be accomplished in such a manner as to insure that the wire, during shipment and storage, will be protected against mechanical injury.
9. APPROVAL: To assure adequate performance characteristics, wire shall be approved by purchaser before use, unless such approval be waived.
10. REJECTIONS: Material not conforming to this specification or to authorized modifications will be subjected to rejection.

CURTIS WRIGHT CORP-WRIGHT AERONAUTICAL DIV
WIRE WRAP ROCKET CASE DEVELOPMENT DEPT 8612

SCHEDULE NO 42

START DATE EVALUATION DATE
2011960 02141961

OPEN SCHEDULE

MILESTONE	ORIGINAL	CURRENT	DAYS EXPECTED	VARIANCE	
ACTIVITY	TARGET PREDICTION	LATE TIME-WKS			
802000099	02141961	00.00	049.6	00.	
0800100001	DEV OPT HEAT TREAT FOR WIRE	8612	1/29/0	112.0	4/15/0 54. 01.
0800100001	112.00		1/29/0	112.0	12051960
0800100005	EFF OF SINGLE DUPL AGING	8612	1/29/0	87.0	4/15/0 54. N 01.
0800100005	87.00		1/29/0	87.0	12051960
0800100010	SELECT PLASTIC	8612	2/01/0	35.0	3/21/0 35. 01.
0800100010	35.00		1/29/0	35.0	6131960
0800100020	DEV ROLLING TECHNIQUES	8612	3/08/0	12.0	3/23/0 12. 01.
0800100020	0880100020		3/04/0	12.0	11231960
0800100025	METHODS DEVEL INSPECT WIRE	8612	3/08/0	27.0	5/05/0 43. 01.
0800100025	0800100020		3/22/0	27.0	1041961
0800200001	PROCURE ROLLS- 2 SHAPES	8612	1/29/0	26.0	3/23/0 37. 01.
0800200001	26.00		1/29/0	26.0	6011960
0800200005	PROCURE DIES-CHANNEL SHAPE	8612	1/29/0	42.0	3/30/0 42. 01.
0800200005	42.00		1/29/0	42.0	9261960
0800200010	PROC ROUND WIRE-2 VESSELS	8612	2/24/0	15.0	3/30/0 25. 01.
0800200010	0880200010		2/24/0	15.0	9261960
0800200011	PROC O RINGS MIL-G-5510	8612	3/01/0	25.0	5/16/0 53. 01.
0800200011	0880200050		3/01/0	25.0	1041961
0800200012	PROC LEATHER BACKUP RINGS	8612	3/01/0	28.0	5/16/0 53. 01.
0800200012	0880200050		3/01/0	28.0	1041961
0800200013	PROC BOLTS	8612	3/01/0	52.0	5/16/0 53. 01.
0800200013	0880200050		3/01/0	52.0	1041961
0800200014	PROC FITTINGS	8612	3/01/0	22.0	5/16/0 53. 01.
0800200014	0880200050		3/01/0	22.0	12281960
0800200015	PROD SAMPLE II WIRE-INTBLK	8612	3/23/0	5.0	3/30/0 25. 01.
0800200015	0800200001		3/23/0	5.0	6081960
0800200015	0880200015			5.0	
0800200016	PROC FITTINGS	8612	3/01/0	22.0	5/16/0 53. 01.
AN929-5S					
AN929-5S					

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0800400001	METH DEVEL-PLASTIC APPL	8612	3/21/0	4/07/0	13.	5/10/0	36.	N	42
0800400001	0800100010 13.00		3/21/0	4/07/0	13.0	12051960	01.		
0800400070	EVALUATE SOLDER	8612	6/20/0	9/14/0	45.	8/19/0	28.		43
0800400070	0800400099 45.00		6/20/0	9/14/0	45.0	2171961	01.		
0800400080	EVAL ULTRASONIC WELDING	8612	6/20/0	8/24/0	31.	8/19/0	28.		44
0800400080	0800400099 31.00		6/20/0	8/24/0	31.0	1041961	01.		
0800400090	EVALUATE TEFLON SAMPLES	8612	6/20/0	10/14/0	67.	9/23/0	54.		45
0800400090	0800400099 67.00		6/20/0	10/14/0	67.0	12281950	01.		
0800400099	EVAL APPLICATION OF PLSTIC	8612	4/01/0	6/20/0	55.	5/02/0	21.		46
0800400099	0800100010 55.00		4/01/0	6/20/0	55.0	9211960	01.		
0800400099	0880400099 55.00				55.0				
0800500001	STRESS ANAL-CHANNEL WIRE	8325	1/29/0	2/19/0	20.	2/19/0	20.		47
0800500001	0800500001 15.00		1/29/0	2/19/0	15.0	9021960	01.		
0800500004	STRESS ANAL-DUMBELL WIRE	8325	1/29/0	2/19/0	20.	2/19/0	20.		48
0800500004	0800500008 15.00		1/29/0	2/19/0	15.0	9021960	01.		
0800500008	STRESS ANAL-ADAPTERS	8325	2/08/0	3/07/0	19.	3/07/0	19.		49
0800500008	0880500008 19.00		2/08/0	3/07/0	19.0	9021960	01.		
0800500010	STRESS ANAL-PIN NO 1	8325	2/08/0	3/07/0	19.	3/07/0	19.		50
0800500010	0880500010 19.00		2/08/0	3/07/0	19.0	9021960	01.		
0800500012	STRESS ANAL-PIN NO 2	8325	2/08/0	3/07/0	19.	3/07/0	19.		51
0800500012	0880500012 19.00		2/08/0	3/07/0	19.0	9021960	01.		
0800500014	STRESS ANAL-PIN NO 3	8325	2/08/0	3/07/0	19.	3/07/0	19.		52
0800500014	0880500014 19.00		2/08/0	3/07/0	19.0	9021960	01.		
0800500030	DESIGN CHANNEL WIRE	8321	1/29/0	3/07/0	25.	3/07/0	25.		53
0800500030	0800500030 25.00		1/29/0	3/07/0	25.0	9021960	01.		
0800500032	DESIGN DUMBELL WIRE	8321	1/29/0	3/07/0	25.	3/07/0	25.		54
0800500032	0800500032 25.00		1/29/0	3/07/0	25.0	9021960	01.		
0800500034	DESIGN ADAPTERS	8321	1/29/0	3/07/0	25.	3/07/0	25.		55
0800500034	0800500034 25.00		1/29/0	3/07/0	25.0	9021960	01.		
0800500035	RELEASE DESIGN	8612	3/07/0	3/07/0	.	3/07/0	.		56
0800500035	0800500099 .00		3/07/0	3/07/0	.0	9021960	01.		
0800500036	DESIGN STAKING PIN NO 1	8321	1/29/0	3/07/0	25.	3/07/0	25.		57
0800500036	0800500036 25.00		1/29/0	3/07/0	25.0	9021960	01.		
0800500038	DESIGN STAKING PIN NO 2	8321	1/29/0	3/07/0	25.	3/07/0	25.		58
0800500038	0800500038 25.00		1/29/0	3/07/0	25.0	9021960	01.		
0800500040	DESIGN STAKING PIN NO 3	8321	1/29/0	3/07/0	25.	3/07/0	25.		59
0800500040	0800500040 25.00		1/29/0	3/07/0	25.0	9021960	01.		

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	0801100015	0801100010	•	10/19/0	10/19/0	•	11/1961	01.
	0801200001	INSTRUMENT VESSEL NO 2 0801000001 3.00	8413	12/23/0	12/29/0	3.0	7/21/0	1. 01.
	0801200001	0801000005 3.00		12/23/0	12/29/0	3.0	2081961	
	0801200001	0801000015 3.00				3.0		
	0801200005	TEST VESSEL NO 2 0801200001 7.00	8413	12/29/0	1/10/1	7.0	7/22/0	1. 01.
	0801200005	MONTHLY REPORT NO. 1 0888000003 5.00	8612	7/15/0	7/22/0	5.0	7/22/0	6. 01.
	0801300010	MONTHLY REPORT NO. 2 0801300010 13.00	8612	7/22/0	8/31/0	13.0	8/22/0	6. 01.
	0801300020	MONTHLY REPORT NO. 3 0801300020 21.00	8612	8/31/0	9/30/0	21.0	9/22/0	22. 01.
	0802000040	COMPILE REPORT NO 4 INFO 0801300030 16.00	8612	9/30/0	10/24/0	16.0	10/21/0	21. 01.
	0802000045	ISSUE MONTHLY REPORT NO 4 0802000040 5.00	8612	10/24/0	10/31/0	5.0	10/31/0	5. 01.
	0802000050	COMPILE REPORT NO 5 INFO 0802000045 16.00	8612	10/31/0	11/23/0	16.0	11/22/0	21. 01.
	0802000055	ISSUE MONTHLY REPORT NO 5 0802000050 4.00	8612	11/23/0	11/30/0	4.0	11/30/0	4. 01.
	0802000060	COMPILE REPORT NO 6 INFO 0802000055 17.00	8612	11/30/0	12/23/0	17.0	12/22/0	21. 01.
	0802000065	ISSUE MONTHLY REPORT NO 6 0802000060 4.00	8612	12/23/0	12/30/0	4.0	12/30/0	4. 01.
	0802000068	TEST TITAN.MIN.35-MIN.65 F 0888000010 10.00	8612	1/03/1	1/17/1	10.0	1/17/1	10. 01.
	0802000099	FINAL REPORT 0800100001 19.00	8612	1/18/1	2/14/1	19.0	10/04/0	35. M 01.
	0802000099	0800100005 19.00				19.0	-2141961	
	0802000099	0800100010 19.00				19.0		
	0802000099	0800200142 19.00				19.0		
	0802000099	0800200148 19.00				19.0		
	0802000099	0800200099 19.00				19.0		
	0802000099	0800300001 19.00				19.0		
	0802000099	0800400099 19.00				19.0		
	0802000099	0800500099 19.00				19.0		
	0802000099	0800900001 19.00				19.0		
	0802000099	0800900005 19.00				19.0		
	0802000099	0801000001 19.00				19.0		

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	34.00	/ /	42.0	10281960	42.	01.	136
0880700030	DUMMY JOB 8-01	1/29/0	3/30/0	42.0	10281960	42.	01.
0880800001	DUMMY JOB	2/01/0	7/01/0	108.	7/01/0	108.	137
0880800045	DUMMY JOB	1/29/0	7/01/0	108.0	11111960	108.	01.
0880800045	DUMMY JOB	1/29/0	6/30/0	107.	1111961	107.	01.
0881000001	DUMMY JOB 10-1	1/29/0	6/30/0	107.0	1111961	107.	01.
0881000001	DUMMY JOB	1/29/0	7/05/0	109.	7/05/0	109.	01.
0888000001	DUMMY JOB	1/29/0	7/05/0	109.0	10211960	109.	01.
0888000002	DUMMY JOB	1/29/0	7/11/0	113.	7/11/0	113.	01.
0888000002	DUMMY JOB	1/29/0	7/11/0	113.0	12061960	113.	01.
0888000003	DUMMY JOB	1/29/0	7/15/0	117.	7/15/0	117.	01.
0888000003	DUMMY JOB	1/29/0	7/15/0	117.0	9231960	117.	01.
0888000004	DUMMY JOB	1/29/0	9/06/0	138.	9/06/0	138.	01.
0888000004	DUMMY JOB	1/29/0	9/06/0	138.0	12011960	138.	01.
0888000005	DUMMY JOB	1/29/0	9/19/0	147.	9/19/0	147.	01.
0888000005	DUMMY JOB	1/29/0	9/19/0	147.0	11111960	147.	01.
0888000006	DUMMY JOB	1/29/0	10/05/0	159.	10/05/0	159.	01.
0888000006	DUMMY JOB	1/29/0	10/05/0	159.0	11091960	159.	01.
0888000007	DUMMY JOB	1/29/0	10/24/0	172.	10/24/0	172.	01.
0888000007	DUMMY JOB	1/29/0	10/24/0	172.0	12081960	172.	01.
0888000008	DUMMY JOB	1/29/0	11/17/0	189.	11/17/0	189.	01.
0888000008	DUMMY JOB	1/29/0	11/17/0	189.0	-11171960	189.	01.
0888000009	DUMMY JOB	1/29/0	12/19/0	210.	12/19/0	210.	01.
0888000009	DUMMY JOB	1/29/0	12/19/0	210.0	1201961	210.	01.
0888000010	DUMMY JOB	1/29/0	1/03/1	219.	1/03/1	219.	01.
0888000010	DUMMY JOB	1/29/0	1/03/1	219.0	1041961	219.	01.
9999999999	DUMMY END JOB FOR PROJECT	2/14/1	2/14/1	.	-2141961	.	01.
9999999999	C801200150	2/14/1	2/14/1	.	.	.	.
9999999999	C800300300	.	.	.	.	.	.
9999999999	C800400070	.	.	.	.	.	.
9999999999	C801000001	.	.	.	.	.	.
9999999999	C801200005	.	.	.	.	.	.
9999999999	C802000065	.	.	.	.	.	.
9999999999	C8C2000099	.	.	.	.	.	.

LIST OF REFERENCES

1. "Aciers Fins and Specieux Francais", No. 21, 1/55, p. 51-54.
2. J. Valenta, Vinute Nadoby, Rozpravy CSAV, C.4, 1957.
3. W. Olgak (Editor), Non-Homogeneity in Elasticity and Plasticity, Pergamon Press, Inc., 1959, p. 211-214.
4. Final Report on "The Evaluation of All-Beta Titanium Alloy Ti-13V-11Cr-3Al for Application to Solid Fuel Propulsion System Chambers", Part I - Metallurgical Studies, Bureau of Ordnance Contract NOrd 18465.
5. Preliminary Proposal for "The Development of Inter-Locked Titanium Wire Rocket Motor Cases", January 15, 1960.
6. Letter Proposal "Revised Program for Follow-on Program for the Development of Inter-Locked Titanium Wire Rocket Motor Cases", February 1, 1961.